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PREFACE

The object of publishing this book is to further the interests of Central Station Heating. During the last three or four years this branch of engineering seems to have received an impetus, and a new era in central station heating development is rapidly dawning. The growth has been slow and the different improvements have come only after hard and persistent effort. That it is rapidly becoming more popular is shown by the fact that the trade journals are devoting so much space to this subject. The operators of central heating plants have only recently formed an associaton which has proven to be one of the greatest boons to the profession.

With this renewed attention and interest in central station heating there is bound to be many new faces in the profession, who will not have to pass through all of the unpleasant experiences some of the rest of us have had to face.

Central station heating, in its broader sense, is properly classed as a public utility, and will eventually be controlled by the different utility commissions. As the development of these plants increase, the field for them will become larger and, consequently, the number of people interested in them will become greater.

The city officers of the various cities will be asked to pass upon heating franchises and should and will want to become familiar with the possibilities and the limitations of central heating plants.

It is with the hope of explaining some of these points that this book is published, thus furthering the interests of the profession. Many of the elementary principles of the science of heating have been omitted, because it seemed unnecessary to explain principles already so widely known and understood.

BYRON T. GIFFORD.

Chicago, January 1, 1912.

THIS book is dedicated to the men with whom I have been associated and whose assistance has materially helped me obtain this information.

These men are:

CHARLES A. GILLHAM
ARTHUR E. DURAM
ALBERT T. CLARK

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Central Station Heating

CHAPTER I.

In General.

CENTRAL heating, or heating from a central plant, is sometimes called district heating. The meaning of the term is self-explanatory. Since it means heating from a point distant from the location heated, it is obvious that transporting and distributing the heating medium are very important branches of this subject. This is entirely true, but the manufacturing or generating of the heat is also of great import.

The transporting of heat is taken up under the subject, "Pipe Line Design."

The distributing of the heating medium is considered under the subject, "Building Equipment."

The manufacturing or generating is discussed in the part devoted to "The Heating Station."

There are two distinct systems of central heating, steam and hot water. These are, of course, entirely different in detail but the general principles involved are very similar and are treated together under the three branches above set out.

Central steam heating was developed first and perfected to a marked degree before hot water heating was tried.

Due, probably, to the success attained in the steam plants, hot water was thought to be a logical substitute for steam and experience has proven that it is. Central steam heating has been in use over 30 years while central hot water heating has been practiced for about 20 years.

Central steam heating in the United States was extensively installed in the middle East, due primarily to the low price of coal. Its growth was gradual and, eventually, this system spread all over the United States. Hot water heating was developed in the middle West where it seems to be more popular than steam to-day. When the natural gas fields in Indiana gave out it was natural that central heating should fill this place and it did to a great extent. Outside of these two territories there is no definite line drawn. We find steam and water plants intermingled with no degree of uniformity. Central heating as a by-product is very attractive financially and either system, steam or water, will give fine results if properly installed and managed and, for that reason, both systems have become popular and have increased in number.

Each system has its advocates. There are many more steam plants than hot water, due, undoubtedly, to the more rapid development in steam heating up to the last few years, Some of the plants originally installed were more or less makeshift propositions or, at least, it seems that way to us to-day, but some of the original plants are still in service and with the same equipment being used and giving good service.

One of the main drawbacks to central heating has been deterioration of the pipe lines, but time has proven many interesting things in this connection. It has established the life of heating pipe lines and this gives us a definite base from which to figure depreciation which, of course, is essential to a financially successful plant.

Central heating as a utility is very similar to any other business. To be successful we must manufacture the heat as economically as possible. We must market it as economically and we must make it attractive both as to price and quality of service.

Since the inception of central heating many improvements have been made in the detail of construction and operation and there undoubtedly will be many more new details developed, but the general principles have remained and always will remain the same. . . .

In the last few years many new devices and appliances have been put on the market, some of them with merit and some of them absolutely worthless. It shows that attention is being given to this branch of public utilities and out of the heap will come a few improvements that will be beneficial. Such has been the history of the development of all industries. The more thought and study given to the subject the more advancement will be made.

The people in general are becoming acquainted with central heating and its possibilities and as this increases so will the demand for these plants increase and their usefulness will likewise increase.

What cities or districts will support a central plant is a question to be decided only by one who is proficient in the work and who has had experience enough to know. No general rule can be given. Each case is a problem all by itself. It depends upon the location of the business to be served, the demand for the service, the cost to manufacture heat in that locality and the relative location of the business and the plant.

One thing that is of interest in this connection is that the ratio of the price of fuel and the probable selling price of the service remains about the same. No matter what the heating company pays for coal the consumers pay in direct proportion and usually sufficiently more to allow the heating company a reasonable profit. For example, in or near the coal fields the heating company pays sometimes less than $1.00 per ton for coal, which, of course, is usually slack and nut, while the consumer pays about $2.00 for soft coal delivered in his coal bins and from $6.00 up per ton for anthracite. In a territory where coal costs the heating company $3.00 per ton the additional price is due to freight and, consequently, the price of coal to the consumer advances also.

The fact that a heating company can use the poorer grades of coal and burn them economically while the isolated plant must use a more expensive grade, makes the difference.

Obviating the smoke nuisance is one of the greatest arguments in favor of central heating. It is, in fact, the only practical solution of the smoke problem. Many things can be said in favor of central heating and only one thing can be advanced against it and that is that it is not always financially successful. That statement is absolutely true but the same thing can be said of any other business and especially any other public utility. The many improvements that have been made have materially helped in this respect but even yet there are places and conditions where a plant will not pay, although they are few and far between. It is very seldom that a by-product plant will not be successful financially. A non-by-product plant can be made to pay but conditions must be right. Putting these non-by-products in promiscuously is a mistake and is only a detriment to the profession. Engineers new in the profession should be very careful in this respect, for nothing but failure can possibly be the result if extreme care is not used in deciding whether or not a non-by-product plant will pan out successfully.

Unit of Measure

The unit of measure used by American engineers in central heating is the British Thermal Unit (B. T. U.), which is the amount of heat required to raise the temperature of 1 lb. of water 1° F. This differs somewhat from other heat units as used by the French and Germans That unit is called the Calorie and is the amount of heat required to raise the temperature of 1 kilogram of water 1° Centigrade. The Pound Caloric is another unit sometimes used. It is the heat required to raise 1 lb. of water 1° Centigrade.

The relative value of the above units is as follows:

1 B. T. U. = 0.252 Calories = 0.454 lbs. Caloric.
1 Calorie = 3.97 B. T. U. = 2.2 lbs. Caloric.
1 lb. Caloric = 1.8 B. T. U. = 0.454 Calories.

The exact B. T. U. is the heat required to raise the temperature of 1 lb. of pure water 1° F. at or near 39.1° F., which is the temperature at which water is most dense, but the usual practice is to accept it to be 1° F. at any temperature or density. This unit is rather small, so central heating engineers have adopted a multiple of this unit which is 1,000 lbs. of steam for steam heating and 1,000,000 B. T. U. for water heating. These units are of about the same value, but not exactly so, and they should be kept separate in one's mind although the B. T. U. in 1,000 lbs. of exhaust steam is approximately 1,000,000 B. T. U., so for that reason, for all practical purposes in central heating, they are considered equal.

Advantages of Central Station Heating

As stated before, there are many things that can be said in favor of central station heating. In discussing these they will be divided under three heads:

1. Advantages to the consumer.
2. Advantages to the community in general.
3. Advantages, as a by-product, to the plant to which it is connected.

Advantages to the Consumer

Cleanliness.—No other method of heating is so clean. There is no coal to be dumped into the cellar with its dust going all over the house. There are no ashes to be handled with their dust and dirt. There is no smoke to contaminate the air and stain the curtains and walls. One thing, however, should be remembered, that wherever there is the least particle of dust in a room it will be picked up with the air circulation and carried to a point over a radiator or register and deposited on the wall. This is easily remedied by the use of a dust shield or a piece of sheer silk draped over the top of the radiator, the silk to match the decoration of the walls or radiator. This shield or silk is easily cleaned once a week and all trouble from marked walls eliminated.

Comfort.—What can be more pleasant than a constant, even heat always there and always ready; plenty of hot water

for domestic purposes such as laundry, bath and kitchen? Any temperature that is desired can be had and at any time of day or night. All that is necessary to do is to turn a valve or, if temperature regulation is used, even that is not necessary. No fires to build and look after. No worry about pipes freezing if away from home at the usual firing hour. No climbing out of bed at 5 A. M. to fix the fire. No coal gas to annoy and cause an irritated throat and nose. No boilers, breechings and chimneys to clean, in fact, "a Florida climate at home all winter," expresses it. There are, of course, many other minor points that can be mentioned in this connection but the author thinks that the above are sufficient to show that from the standpoint of comfort nothing equals central station heating.

Expense.—Central station heating can be used as economically or as extravagantly as the individual taste dictates. If used economically, it will cost less to operate than an individual plant and, if the same space is heated continuously from each system, it will cost less for central heat. This is due to the fact that every heat unit paid for is used. Granting that the central heating bill is larger than the coal bill in some cases, the other items eliminated by central heat and the expense saved in consequence thereof more than offset the difference. There are no ashes to be hauled away. No firemen necessary at one or two dollars per week. No boiler is necessary and consequently there are no grates to replace when burned out with the attending expense as well as the interest on the investment in the boiler.

The doctor bills will be less, due to correct temperature, sufficient warm fresh air and no drafts or chilly halls and floors. Less fire risk and, consequently, the insurance premium should be less, but, unfortunately, the insurance companies are not educated up to the point to deliberately cut down their revenue, although it has been done in some places. At any rate the lessened risk is surely worth considering because no man wants to suffer a loss from fire whether insured or not. As a rule, property being served with central heat is more desirable and more easily sold

or rented than other property and, generally, property along the pipe line is held at a premium over other property. In some cities large signs advertise the fact that certain additions or districts have a central heating plant serving it. The even temperature does not allow the shrinking or swelling of the furniture or woodwork. If for any reason the home has to be shut up for a few days or weeks nothing will freeze or nothing will be hurt while the occupants are away, and, upon returning, the home will be warm and dry and ready to step into.

It is easier to get and retain good and efficient help with central station heat in the house or store. They feel better and have the comforts which they enjoy as much as anyone. In using heat from a central plant the heat is paid for about as used. This obviates paying for coal in the summer or an average of about six months before it is used. While this is not a great saving it amounts to something and is worth consideration.

Advantages to the Community.—The abatement of the smoke nuisance is one of the greatest benefits derived by the city or community which a central heating plant serves. This is really the only logical way to eliminate the smoke problem in a country where coal is the necessary fuel. Although the community derives this benefit, it is not sacrificing anything to get it, for the mains are all underground and there are no unsightly poles or wire used in the system. Property generally increases after a central heating plant is installed, due to the benefits derived from the service. After three to five years a plant is usually handling its capacity and, as the territory to be served is limited, it generally creates a healthy demand for property abutting the heating mains.

Advantages as a By-Product Plant.—In combining any steam generating plant, such as an electric plant, the financial benefits derived by the primary plant are large. It is an admitted fact that the thermal efficiency of an electric plant is very low. Even after the steam is generated 70% to 90% of the steam is exhausted after passing through the prime-mover. If this steam is exhausted to the atmosphere the waste is enormous. If it is condensed

the heat in the exhaust steam is transmitted to the cooling water and liberated, either through the cooling tower or pond. At any rate, it is wasted, but, of course, not so much of it is wasted in the condensing plant because the vacuum maintained increases the power developed per pound of steam and, due to the low temperature of the exhaust, the thermal efficiency of the plant is increased. Then the question arises: "Can a kilowatt of electricity be made under a condensing condition for less money than under a non-condensing condition connected to a heating plant?" Where the electric plant is located so that it can serve a good heating territory, it can make a kilowatt of electric energy for considerable less in conjunction with a heating plant than it can by running alone condensing. It is a problem that should be worked out for each situatio, but, as a general rule, the revenue from the heat sales will more than pay the coal bills after deducting interest, maintenance and depreciation on the heating investment from the heat income. It can be seen, therefore, that the cost per kilowatt ought to be less in the combination plant.

Combining these two utilities then increases the net earnings of each. It increases the load factor of the boiler plant and causes it to operate more economically because of the better load conditions. It increases the heat units utilized and sold. It does not increase the labor cost as the same crew can handle both. It increases the electrical output because it does away with the isolated electric and power plants.

If the central plant can serve its patrons with heat, light and power it is not half so difficult to get this business because, as a rule, the owners of the isolated plants can buy these commodities from the central plant for less money than they make them themselves, but if heat is not furnished them by the central plant they can not afford to buy electricity and make their own heat, as they heat with the exhaust steam from their own plant which, they naturally and correctly figure, costs them practically nothing. This kind of business materially helps the electric plant because it increases its load and its net earnings.

One of the greatest arguments in favor of the combination plant is the fact that it keeps out competition. If an electric plant is not selling heat in its city or community it is only a matter of time before the people will demand a heating plant. If a heating plant alone is contemplated it is seldom that it will show sufficiently large returns upon its investment to make it attractive to capital; consequently agitation will soon develop that demands a competing electric plant in order to bring out the heating plant and, nine times out of ten, the new electric franchise will be granted, which, of course, is not only a detriment to both companies but also to the city in general, for there is never but one answer to a condition of this kind. As long as the electric company is properly serving the community with heat, light and power there is little chance of competition. The same condition prevails relative to the isolated plants operating without a franchise in a block or portion of a block. This business could all be obtained by the central plant if that plant could serve it.

In general, the combining of these two utilities is very satisfactory and advantageous to both.

CHAPTER II.

Pipe Line Losses

THERE are three factors that affect the loss in pipe line operation, and all three are very important: loss from radiation, loss from friction and loss from leaks. These will be taken up separately.

First, Loss from Radiation. This line loss in any underground system is practically constant in steam heating, while in water heating it is proportional to the temperature of the heating medium, and, in both cases, is entirely independent of the per cent. of the capacity being carried in the mains or laterals. In all cases the insulation and pipe line construction affect it to a great extent, especially the drainage of the pipe line to remove, or, better yet, to keep away the surface water or backup water from flooded sewer systems. The depth of the pipe underground also affects the radiation loss.

The author has used as a unit for basing his calculations, 1 sq. ft. of pipe surface underground, including also each square foot of surface in the fittings and specials, such as expansion joints, and all results are given in the radiation loss per square foot of surface per hour. In this work the following table will be found useful for wrought iron and steel pipe:

Diameter of pipe, inches.	Square feet per lineal foot.
⅛	0.106
¼	0.141
⅜	0.176
½	0.219
¾	0.276
1	0.344
1¼	0.434
1½	0.497
2	0.621
2½	0.752
3	0.916
3½	1.047
4	1.178
4½	1.309
5	1.456
6	1.734
7	1.996
8	2.249
9	2.436
10	2.814
12	3.254
14 O. D.	3.665
15 O. D.	3.760
16 O. D.	4.188
18 O. D.	4.712
20 O. D.	4.736
22 O. D.	5.759
24 O. D.	6.283

The above table is derived from the formula:

$$\text{Square feet} = \frac{\text{External Diam. in inches} \times \pi}{12}$$

The external surface of the fittings and specials should be calculated. There are so many different sizes and shapes it would be impossible to tabulate their surfaces here. Knowing the number of square feet of surface underground

and the amount of heat lost per square foot per hour, it is a simple matter to figure the heat lost in any underground system by the formula (H = Heat lost in pounds of steam)

$$H = \text{square feet} \times C.$$

Where C is a constant, depending upon the insulation and construction of the pipe line, as well as the temperature of the heating medium.

H. D. Spencer, of Detroit, in Proceedings National District Heating Association for 1910, gives the values for C as follows:

0.051 for 5 lbs. steam lines.
0.086 for 20 lbs. steam lines.

These values are for 4 in. sectional wood log (segmental).

C. R. Bishop, in Proceedings N. D. H. A. for 1910, gives values for C as 0.045, but does not state the pressure or style of insulation. Evidently this value is for the same style of insulation as that reported by Mr. Spencer, but at a lower steam pressure, probably 3 or 4 lbs. These two observations being so close it is probable that the tests were made under about the same conditions.

Tests that the author has made have given him various values for C, from 0.15 to 0.0292, showing a great range of value.

A test on three thicknesses of 2 in. hemlock, with paper lining and shavings, showed, while the insulation was in good physical shape, a value for C as low as 0.0292, but this condition gradually became worse as the insulation became wet and deteriorated. This value is very low and is not often recorded.

The author made a test on the following pipe line with results as follows:

306 ft. 12 in. pipe line.
300 ft. 10 in. pipe line.
481 ft. 8 in. pipe line.
288 ft. 6 in. pipe line.

The value for C was found to be .0362 during one 98-hour test when the temperature outside was between 20° and 30° F. Steam pressure 3 lbs.

This pipe line was insulated with 1½ in. of asbestos and wool felt and thoroughly water-proofed, as well as underdrained, and this protected on the outside by a 4 in. partition tile conduit, which had a 3 in. air space in it, and placed 4 to 5 ft. underground; i. e., the pipe was 4 to 5 ft. underground.

There is, therefore, only one conclusion we can come to in this case, and that is, that C is a decidedly variable quantity. There is no accurate way of arriving at a value of C except by experiment, but the author uses values given below in his calculations:

Description of insulation and construction	Value of C*	
	Steam at 5 lbs.	Water average
Hemlock lumber, three 2 in. thicknesses, paper and shavings....1st year	0.03	0 02
Same....3rd year	0.05	0.03
Same....5th year	0.08	0.06
Same....8th year	0.10	0.07
Hemlock lumber, two 2 in. or three 1 in. thicknesses, no paper or shavings....1st year	0.05	0.03
Same....3rd year	0.07	0.05
Same....5th year	0.09	0.06
Same....8th year	0.10	0.07
4 in. segmental wood log, tin lined, well underdrained. 1st year and as long as in good condition....	0.04	0.025
4 in. concrete conduit, 1 in. covering....	0.08	0.06
4 in. concrete conduit, 1½ in. covering....	0.05	0.03
4 in. concrete conduit, 2 inch. covering....	0.04	0.025
4 in. brick conduit, 1 in. covering....	0.08	0.06
4 in. brick conduit, 1½ in. covering....	0.05	0.03
4 in. brick conduit, 2 in. covering....	0.04	0.025
4 in. partition tile conduit, 1 in. covering....	0.07	0.055
4 in. partition tile conduit, 1½ in. covering....	0.04	0.025
4 in. partition tile conduit, 2 in. covering....	0.034	0.020
Two 1 in. thicknesses lumber with 3 in. concrete envelope....	0.05	0.03
Tunnel construction 2 in. covering....	0.045	0.030

*Values of C are given in lbs. of steam. Multiply this value by 1,000 for heat units value.

All of the foregoing values are used for a dry condition. If wet, it is difficult to assume a value for C.

These values are not absolutely accurate and are not given with that intention, but will be found to be sufficiently correct for estimating purposes.

Efficiency of Underground Covering. From the above table the efficiency of any covering there given can be approximated. The efficiency of a covering is the percentage of heat saved by using the covering. In central station heating work there are two other things that increase the insulating qualities of the covering. (1) The conduit, if used, and (2) the soil over and around the conduit or covering. It is obvious a pipe line laid 10 ft. underground will not lose as much heat per hour as one laid 2 ft. underground. The values given in the above table are for pipe line from 3 to 5 ft. underground; i.e., to center of pipe.

The heat unit loss of bare pipe is 2.7 B. T. U. per square foot per hour per degree difference in temperature (Fahrenheit).

We can assume that the temperature surrounding a bare pipe, if used underground would be 40° F., and the temperature of the heating medium, if steam, at 5 lbs. pressure is used, to be 226° F.

$$(226—40) \times 2.7 = 502.2 \text{ B. T. U. or } 500 \text{ Approx.}$$

The efficiency of 4 in. segmental wood log construction would be then as follows:

From table of B. T. U. loss=0.040×1000=40 B. T. U. We lose, therefore, 40 B. T. U., and save 460 B. T. U. and our efficiency is, therefore,

$$\frac{460}{500} = 92\% \text{ of the steam lost in a bare pipe.}$$

This calculation allows us to figure the heat unit line loss for steam pressures other than 5 lbs.

As an example: figure the heat unit loss for a 25 lb. steam line using 4 in. segmental wood log covering. From the above we see it is 92% efficient.

Bare pipe at 25 lbs. pressure has a temperature of 266° F.

(266—40)×2.7=610.2 or 610 approx.
92% of 610=561 B. T. U.
Value of "C"=8%=48.8 B. T. U.
=0.0488 lbs. of steam.

The fact should not be overlooked that these values of "C" are for dry conditions, with the covering in very good shape, the pipe line well installed, and completely insulated throughout.

Some Important Items Affecting Line Loss from Radiation.

Drainage. Next to insulation in importance comes underdrainage in its effect on radiation loss. Water will convey heat about eight times as fast as air when confined and for that reason we should try to keep all water, surface or otherwise, away from the insulation and pipe. This can be done by thoroughly waterproofing the conduit and by carrying away whatever water accumulates near the conduit. If the pipe line is laid in a porous soil, such as sand or gravel, the waterproofing of the conduit is sufficient, but in a clay soil some means to carry off the water is necessary.

Lumber insulation will last longer in a clay soil than in a sandy soil, due to the fact that the different conditions of wet and dry will eventually rot the lumber. Lumber under any conditions must be kept dry to be a good heat insulator.

Manholes. Manholes lose more heat per square foot of pipe surface than any other part of the underground system, due of course to the lack of covering. For that reason as few manholes as is consistent should be built. On the other hand, manholes should be over all moving parts such as expansion joints, variators, valves, etc., because of their tendency to leak and cause a very bad condition. A steam leak not only loses heat but it rusts the pipe and deteriorates the insulation and is liable to affect a large section of line before it is discovered.

Heat Losses Due to Leaks. This cause of loss is probably more serious than is at first supposed. According to Napier's Approximate Rule.

$$S = \frac{Pp \times A}{70} = \text{Pounds of steam per second which will pass through a hole.}$$

where Pp = Pressure absolute in the pipe.

A = Area of opening.

$$S = \frac{Pp \times A \times 3600}{70} = \text{Pounds of steam lost per hour.}$$

Assume a ¾ in. hole in a pipe or fitting or assume a number of smaller holes whose aggregate leakage is equal to ¾ in. in diameter in a 5 lb. steam line.

$$S = \frac{19.7 \times .44 \times 3600}{70}$$

$$= 445.7 \text{ lbs. per hour.}$$
$$= 10{,}969 \text{ lbs. per day.}$$
$$= 320{,}904 \text{ lbs. per month.}$$

Assuming, also, an evaporation of 7 lbs. water per pound of coal, we have:

45,843 lbs. coal per month, or 22.9 tons.

From this it is quickly seen that it is absolutely necessary to have a tight pipe line for economical operation.

The same case holds true in hot water heating.

Assume the loss of 1 bbl. or 400 lbs. of water per hour from the flow line at a temperature of 170° F. and under ordinary conditions the water is raised from 40° to 170° F. from the well to the flow line, or 130° F.

$$400 \times 130 = 52{,}000 \text{ B. T. U.}$$

If this leak should be on the return line it would be $400 \times 110 = 44{,}000$ B. T. U. per hour that we would lose, which, assuming 7,000 available B. T. U. per pound of coal, would show us the following result at the coal pile:

1 bbl. leakage per hour from flow line = 2.67 tons per month.

1 bbl. leakage per hour from return line = 2.19 tons per month.

This shows us the cost of a small leak and it would pay well to fix it and fix it at once.

A tell-tale pump or indicator should be installed on every water pipe line at the station to detect any leak. Very little trouble is to be expected from the loss of water from theft owing to the condition of the water after circulating, but the tell-tale will indicate any leak and should be installed.

Loss Due to Friction

Steam Mains.—Many different formulas and tables are in use for figuring the loss due to friction. The velocity, quantity of steam flowing, as well as the pressure, affect the friction on the sides of the pipe and, if the steam flows in the opposite direction to the condensation, we add another factor which materially affects the friction loss, due to the skin friction of the water and the steam, as well as the partial choking of the pipe area, on account of the depth of water necessary to give the condensation sufficient head to drain back.

As a rough method of estimating friction loss in heat units use may be made of the pipe capacity curves here given.

Multiply the pressure drop given on the curves (Charts Nos. 1, 2 and 3) by the factor or constant 0.2. This will give the number of heat units lost per pound of steam. This product multiplied by the number of pounds of steam per hour will give the total heat units lost per hour in low pressure steam mains.

By referring to Pipe Capacity Curve No. 3, page 29:
1000 lbs. steam per hour in a 4-in. pipe 1000 ft. long.

Loss $= 1.2 \times 0.2 \times 1000 = 240$ B.T.U.
Same in a 3-in. pipe $= 7.3 \times 0.2 \times 1000 = 1460$ B.T.U.
Same in a 3½-in. pipe $= 2.5 \times 0.2 \times 1000 = 500$ B.T.U.

Water Mains.—We have about the same conditions affecting the friction in water pipe lines that we have in steam pipes, the velocity, the quantity and the pressure. The natural laws of gravity also affect the flow.

To estimate the loss in B.T.U. in the friction of water pipes, refer to the pipe curves for water and use the following formula:

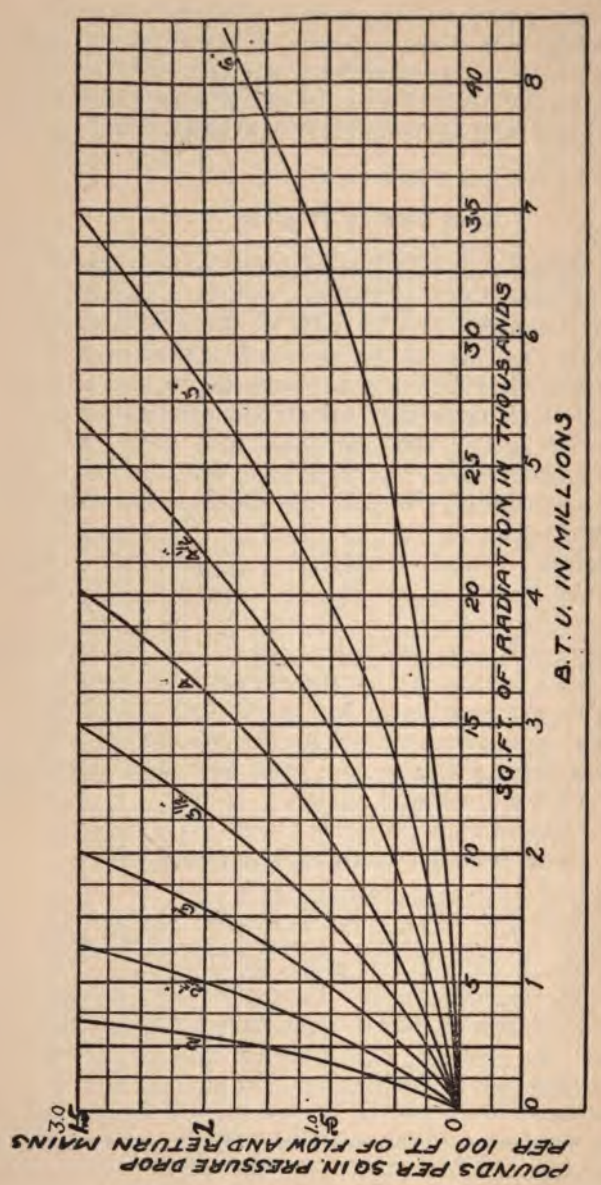

FIG. 1. (CURVE 1)— PRESSURE DROP IN HOT WATER MAINS, 2-IN. TO 6-IN., BOTH INCLUSIVE.
Based on 1 Square Foot of Radiation Emitting 200 B. T. U. per Hour.

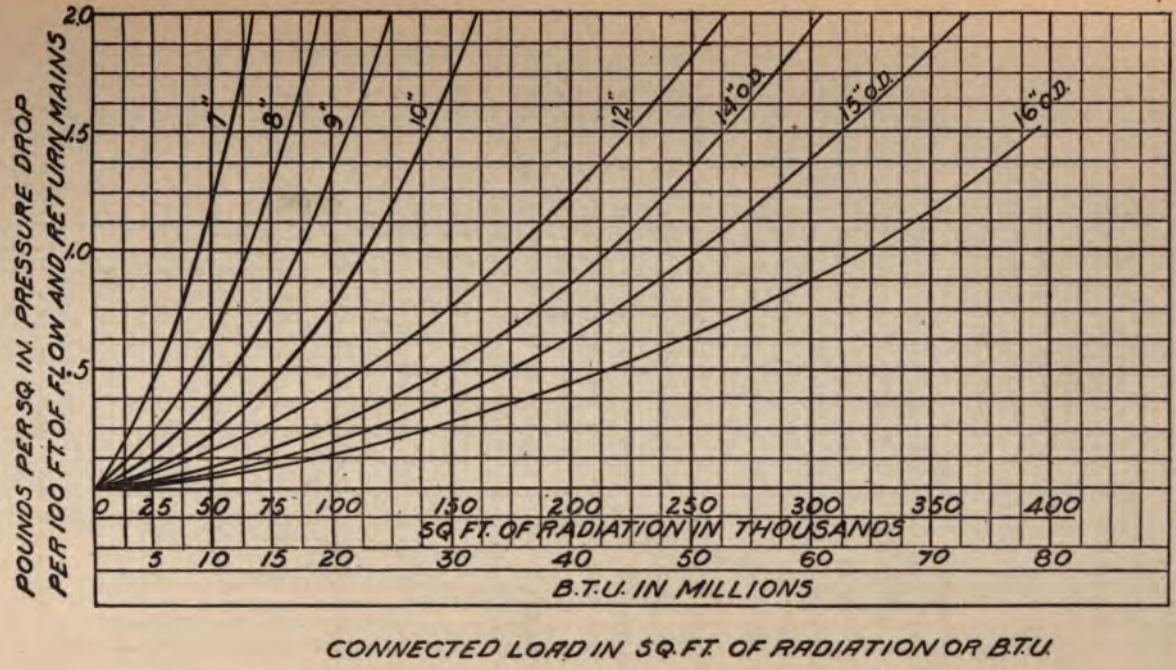

FIG. 2. (CURVE 2)—PRESSURE DROP IN HOT WATER MAINS, 7-IN. TO 16-IN., BOTH INCLUSIVE.
Based on 1 Square Foot of Radiation Emitting 200 B. T. U. per Hour.

Example:—15,000 sq. ft. radiation, 5-in. pipe 1000 ft. long. From curve, friction drop is 0.52 lbs.

Loss in B.T.U. = 0.046 × F × R × L

0.046 = a constant.

F = friction drop in lbs. per 100 ft.

R = radiation shown by table.

L = length in 100 ft.

In the case cited,

B.T.U. loss by friction = 0.046 × 0.52 × 15,000 × 10 = 3588 B.T.U. per hour.

The value of this constant 0.046 takes into consideration using the exhaust steam from the pumps in the heating system and also the usual circulating pump efficiency, which, in reciprocating pumps, is very low.

Combining the Losses from Radiation and Friction to Find the Most Economical-Sized Pipe Line.

Steam.—Given 1000 lbs. per hour to carry 1000 ft.

From our pipe curve for steam (Chart No. 3) we see that a 3-in., 3½-in., 4-in. and 4½-in. pipe will do this nicely but we must determine the most economical one.

Loss by friction according to formula:

3 -in. line = 1460 B.T.U.
3½-in. line = 500 B.T.U.
4 -in. line = 250 B.T.U.
4½-in. line = 130 B.T.U.

Radiation loss according to formula:

Value of C = 0.05

Assuming 1 lb. of steam = 1000 B.T.U.

3 -in. line = 45,800 B.T.U.
3½-in. line = 52,350 B.T.U.
4 -in. line = 58,900 B.T.U.
4½-in. line = 65,450 B.T.U.

Total loss:

3 -in. line = 47,260 B.T.U.
3½-in. line = 52,850 B.T.U.
4 -in. line = 59,150 B.T.U.
4½-in. line = 65,580 B.T.U.

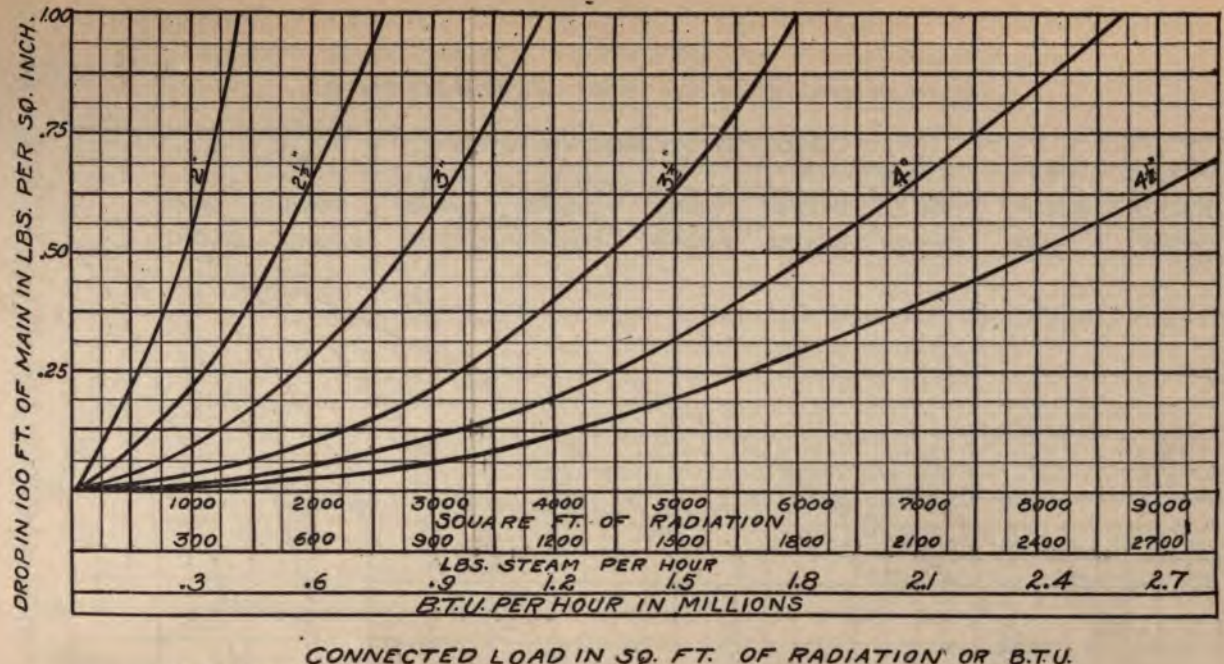

FIG. 3. (CURVE 3)— PRESSURE DROP IN STEAM MAINS, 2-IN. TO 4½-IN., BOTH INCLUSIVE.
Based on 0.33 lbs. Steam per square foot of Radiation per Hour. Also 1 lb. = 1000 B. T. U. Radiation Loss = 0.05 lbs. of Steam per Hour per Square Foot of Underground Surface.

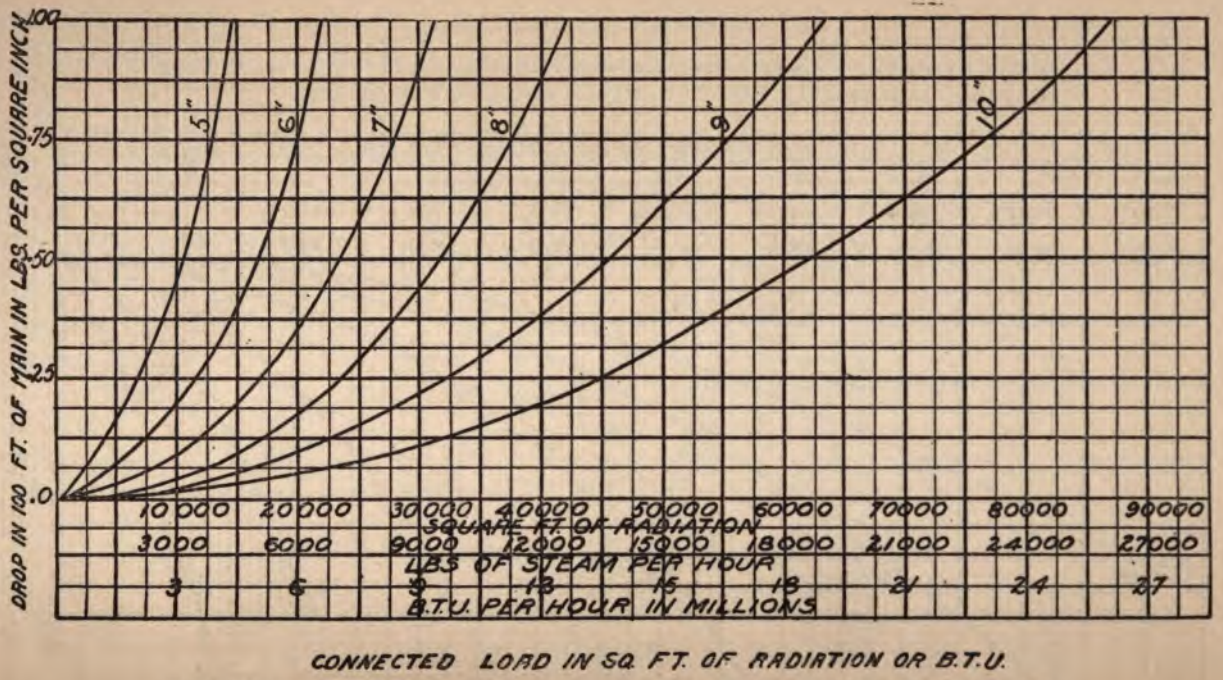

FIG. 4. (CURVE 4)—PRESSURE DROP IN STEAM MAINS, 5-IN. TO 10-IN., BOTH INCLUSIVE.

Based on 0.33 lbs. Steam per Square Foot of Radiation per Hour. Also 1 lb. of Steam = 1000 B. T. U. Radiation Loss = 0.05 lbs. of Steam per Square Foot of Underground Surface.

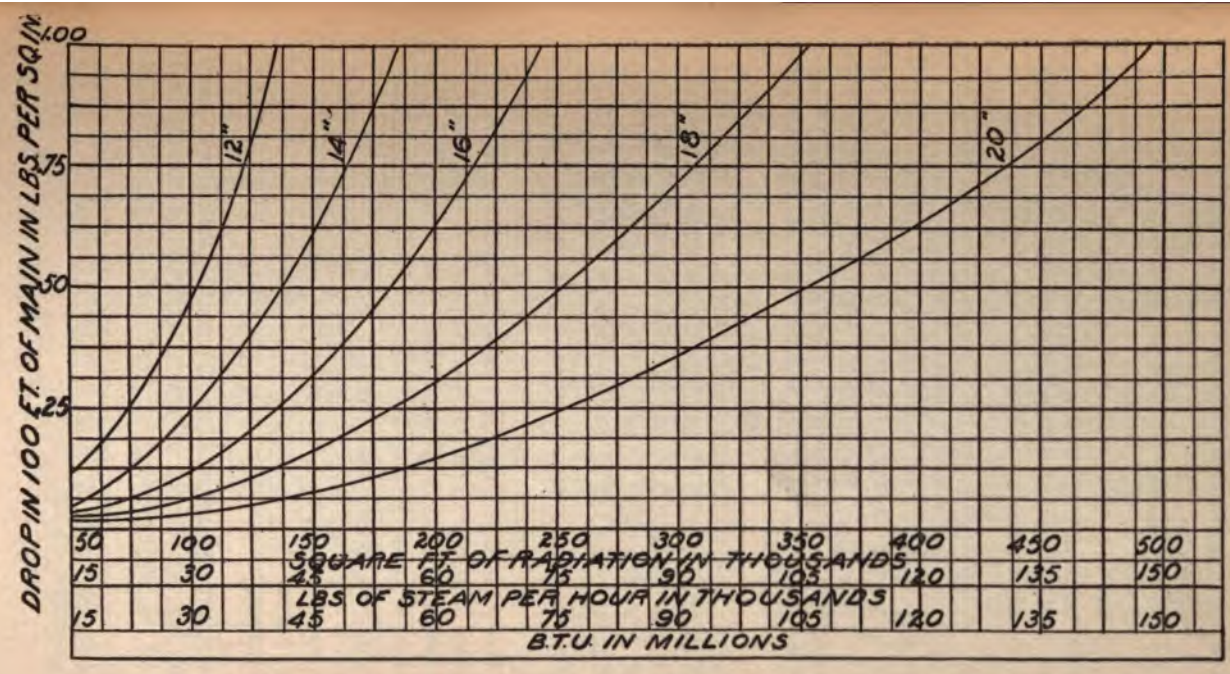
DROP IN 100 FT. OF MAIN IN LBS. PER SQ.IN.
1.00
.75
.50
.25
12"
14"
16"
18"
20"
50 100 150 200 250 300 350 400 450 500
SQUARE FT. OF RADIATION IN THOUSANDS
15 30 45 60 75 90 105 120 135 150
LBS. OF STEAM PER HOUR IN THOUSANDS
15 30 45 60 75 90 105 120 135 150
B.T.U. IN MILLIONS
CONNECTED LOAD IN SQ.FT. OF RADIATION OR B.T.U.

FIG. 5. (CURVE 5)—PRESSURE DROP IN STEAM MAINS, 12-IN. TO 20-IN., BOTH INCLUSIVE.
Based on 0.33 lbs. Steam per Square Foot of Radiation per Hour. Also 1 lb. of Steam = 1000 B. T. U. Radiation Loss = 0.05 lbs. of Steam per Square Foot of Underground Surface.

This shows conclusively that the 3-in. line is the most economical to run, provided it does not affect our station conditions by causing excessive back pressure. From our pipe curve we find it will cause a drop of 7.3 lbs., which, with 1 lb. at the end of the line, means 8.3 lbs. at the station. If this does not affect our engines a 3-in. line would be the one to run, but, if we must keep our back-pressure below 5 lbs., we would be obliged to run a 3½-in. line.

Water.—Combining the friction loss and radiation loss in water pipe lines, we will assume a case.

Given 15,000 sq. ft. of radiation to heat 1000 ft. distant.

From our pipe capacity tables (Chart No. 1) we find that a 4-in., 4½-in., 5-in. or 6-in. pipe will handle this work. Asssume a pipe line loss, owing to class of insulation used, to be 30 B.T.U. per square foot of pipe surface per hour.

Radiation loss = from formula (H = sq. ft. × C).

4 -in. line = (1.178 × 30) × 1000 = 35,340 B.T.U.
4½-in. line = (1.309 × 30) × 1000 = 39,270 B.T.U.
5 -in. line = (1.456 × 30) × 1000 = 43,680 B.T.U.
6 -in. line = (1.734 × 30) × 1000 = 52,020 B.T.U.

Friction loss = from formula (L = 0.046 x F × R × L).

4 -in. line = 0.046 × 1.75 × 15,000 × 10 = 11,775 B.T.U.
4½-in. line = 0.046 × 1.1 × 15,000 × 10 = 7,590 B.T.U.
5 -in. line = 0.046 × 0.52 × 15,000 × 10 = 3,588 B.T.U.
6 -in. line = 0.046 × 0.25 × 15,000 × 10 = 1,725 B.T.U.

Combined radiation and friction losses.

4 -in. line = 47,115 B.T.U.
4½-in. line = 46,860 B.T.U.
5 -in. line = 47,268 B.T.U.
6 -in. line = 53,745 B.T.U.

These figures show us that the 4½-in. line is the most economical line to install, but how our line pressures will be affected is important and must be taken into consideration.

The 4-in. line will give us a pressure drop in our differential pressure of 17.5 lbs.

The 4½-in. line will give us a drop of 10 lbs.
The 5 -in. line will give us a drop of 5.2 lbs.
The 6 -in. line will give us a drop of 2.5 lbs.

Therefore, if this line is to be connected at a point of large differential, as at a point near the station, we can afford to run the 4½-in. pipe, but, if we are to connect it at a point of low differential, as at the end of the system, the 5-in. would be the better size to install and it might be economy to install the 6-in. line.

From the above calculations on combined losses of steam and water a few conclusions can be deduced:

FIRST: In steam pipe lines the radiation loss is much more important than the friction loss.

SECOND: In water pipe lines the friction loss is decidedly more than in steam pipe lines, but still it is not as large as the radiation loss.

The heat we lose from friction is not lost in the pipe line, with a small exception, due to the fact that it tends to increase the temperature of the line and its contents and thus increase the radiation loss. Where we lose this heat is at the station, due to the increased pressure that is necessary to properly circulate the heating medium, whether it be steam or water. This is proven by the fact that if we circulate water fast enough in a small system we can eventually raise the temperature of the water in the system a considerable amount. In this case we obtain the heat from the circulating pump and transmit it to the water through the friction in the piping.

Another general conclusion we can deduct is that the less our friction loss, the less our pipe line loss in a given size line, for the radiation loss remains constant.

As can be readily comprehended, in every pipe line system we have a very nice problem to figure on and one that requires study and thought.

Of the two losses, that from friction and that from radiation, the radiation loss is much the greater and from the above formulas we can tell how much can be lost or saved in the pipe line insulation and construction.

Knowing the cost of 1000 lbs. of steam in a steam plant or the cost per 1,000,000 B.T.U. in a water plant,

it is easy to figure how much can be spent on insulation to reduce the factor "C."

For example: Assume our pipe line loss to be 0.05 lbs. per square foot per hour.

Assume 1000 lbs. steam costs to generate 25c.

Steam per square foot per hour for 5200 hrs. = 5200 × 0.05 = 260 lbs. steam per season = 6.5c.

With a pipe line loss of 0.04 lbs. steam per square foot per hour, for 5200 hours we would have a charge 5.2c. or a saving of 1.3c. per season per square foot of pipe line surface for every 1/100 lbs. of steam saved.

Assume a pipe line with 60,000 sq. ft. of surface; 1/100 lbs. of steam saved by increasing our insulation would save us $780.00 per year or 10% on $7,800.00 or 10% on 13c. per square foot of surface, which would show a saving as follows on the various sized lines:

The following is a table showing the amount of money it would be profitable to spend each year to increase the insulating qualities of the pipe line so as to save 1/100 lb. of steam per hour per square foot.

Diameter of Line, in Inches.	Cents per Lineal Foot.
3	11.9
4	15.3
5	18.9
6	22.5
8	29.25
10	36.5
12	42.25
14 O.D.	47.64
16 O.D.	54.44
20 O.D.	61.57

From the above table we can figure how much more one insulation is worth than another and also how much we can afford to spend to increase the insulating qualities of our pipe line system.

For example: A 16-in. steam line, covered with wood boxing, badly rotted (C = 0.10) is costing us about three times too much to operate and we could afford to spend

to bring our line loss to 0.04 (6 × 54.44c.) = $3.27 per foot per year. If we repair this insulation or replace it with new so that it will last 10 years, we could afford to spend $32.70 per foot to do it. This shows how valuable and essential, efficient and durable insulation is.

As pipe line losses from radiation are by far the greatest loss in central station heating, it is at this place where we can afford to look for leaks and can afford to fix them. The operating manager who is overlooking this point is blind to his own interests.

CHAPTER III

Pipe Line Design

IN the design of central station heating pipe line two things must be definitely determined: the location of the central station and the amount and location of the business to be served. The location of the power house should be governed by the location of the territory to be served, also the urgent need of a switch for fuel purposes. In fact, about the same things determine the location of a heating plant as would determine the location of any central station. The business to be served is, in many cases, very difficult to ascertain, owing to the uncertain growth of the city, and the fact that it is necessary, for financial reasons, to have, if possible, every foot of pipe line earning some return on the money invested in it. New buildings will be built and the present buildings may be enlarged, so a great deal of care and thought should be spent on this part of the design.

A method the author has used for some time with very satisfactory results is as follows: First, prepare a map of the city drawn to scale, and of a convenient size to carry in the field; sometimes it is necessary to divide the map into two or more parts. Show on this map all streets and alleys, and the relative elevation of each street intersection. Note also the paved streets and the kind of pavement. On the map show also each building and its location and mark the kind of building, whether business, church. residence, bank, hotel, etc.; together with this, the

number of cubic feet of space in each building. As a general rule 100 cu. ft. of space requires 1 sq. ft. of direct steam radiating surface or 300 B. T. U. per hour or approximately 0.3 lb. of steam per hour. In hot water heating 60 cu. ft. of space requires 1 sq. ft. of direct water radiation or 180 B. T. U. per hour. After this information has been secured, make a survey and a careful study of the different sections of the city, noting on the map the best sections for the central heating plant to serve, taking into consideration at all times, the future growth of the city. It is in this part of the design that experience is needed, and many times the engineer will find he has made a poor guess. The word guess is used because, in many cases, central heating plants have grown beyond the wildest dream of its designer.

In a good residence section of homes, owned by people of moderate wealth, 90% of the present business will be connected within five years. Any vacant lots in such a section should be considered as built up with buildings to compare favorably with the surrounding buildings.

In a business section 60% to 70% of the available business will be connected within five years. This is greatly dependent upon the kind of heat to be sold, whether steam or water, and whether the buildings are already equipped for heating with steam or water. As a rule, steam service is more popular in business sections, while, in residence sections, water seems to be more universally sought, although either system will operate very satisfactorily.

The rapidity with which business is connected to a plant depends upon the company managing the property, but the designer should anticipate a rapid growth in the number of consumers and the amount of business. After having determined the location and amount of business and the central station location, work on the detail design can be started.

Commence by laying in the lines on the map, in such a way as to reach the greatest amount of business on the least number of feet of pipe line. This requires oftentimes the cut-and-try method. Whether to use alleys or streets depends upon two things: first, the relative cost of street

and alley construction; second, the location of the buildings relative to the street or alley. The author has found that alley construction, other things being equal, will cost 13% to 30% more for the labor, owing to the difficulty of working in such a narrow place. Another thing affecting the cost of construction is the pavement which has to be taken up and relaid.

In most cities the heating companies are obliged to bring their service pipes to the curb line in the street, and to the property line in the alleys. This item of expense should not be overlooked, for in a wide street the average cost for service lines will more than eat up the saving in labor effected by street construction.

We will assume for calculation a good residence section, as shown in Fig. 6, Block 2. We assume that we will get 90% of the available business in this block, which is ap-

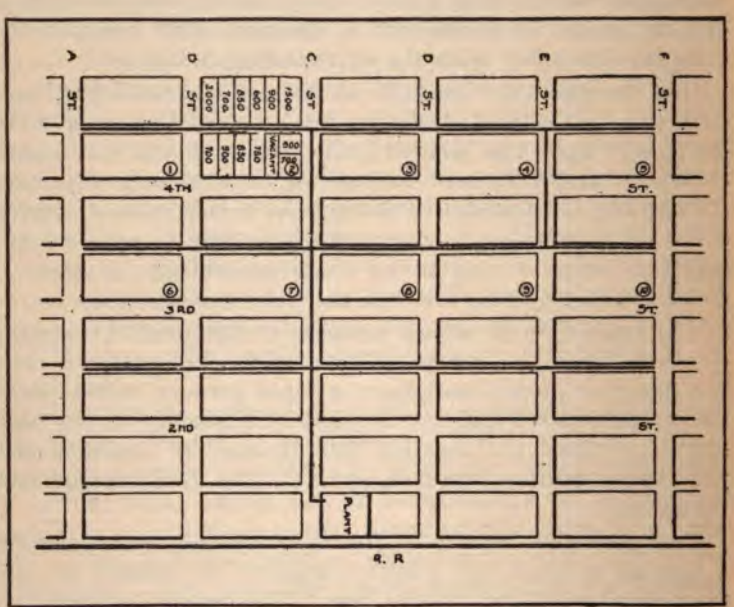

FIG. 6—BLOCK PLAN OF TYPICAL RESIDENCE SECTION IN A CITY

proximately 10,500 sq. ft. of water radiation, or approximately 6,300 sq. ft. of steam radiation.

We are obliged to allow for future extensions for Block No. 1, and possibly more yet, but in this lay-out we will assume that eventually Block No. 1 will equal Block No. 2. Block No. 2 is 400 ft. long, and Block No. 3 is the same length. We have altogether 21,000 sq. ft. of water radiation to handle, but some of it will be taken off in the first 100 ft., and about 25% of it will be served by the time we reach the center of Block No. 2; 25% more will be taken off by the time we reach B street, and 25% off when we reach the center of Block 1; the last 25% by the time we reach the west side of Block No. 1.

In designing a central hot water pipe line, the author has found it better practice to throw most of the line friction in the trunk line and to have the friction loss in the laterals very small, and to make the friction loss in the laterals in proportion to the circulating pressure (difference in pressure) at the point the lateral begins. As an example, we will assume that at the point of the lateral for Blocks No. 1 and No. 2 the circulating pressure is 5 lbs. Now we must have at least 1 lb. of circulating pressure at the end of the lateral, therefore we can lose 4 lbs. in friction between the ends of the lateral, or 1 lb. per 200 ft. We then have the following condition:

First	200 ft. of line must handle	21,000	sq. ft. of radiation.
Second	200 ft. of line must handle	15,750	sq. ft. of radiation.
Third	200 ft. of line must handle	10,500	sq. ft. of radiation.
Fourth	200 ft. of line must handle	5,250	sq. ft. of radiation.

From curve No. 1 we find a 6-in. pipe will handle 21,000 sq. ft. with less than this friction loss, and 5-in. will handle 15,750 sq. ft., a 4½-in. will handle 10,500 sq. ft. with less than a ½-lb. loss, and a 3½-in. pipe will handle 5,250 sq. ft. of radiation with about the same friction loss.

A rule the author has followed is never to run a smaller water main than 3-in. in the initial lay-out; this will always allow for some future extensions.

In figuring a branch line off of a lateral, consider the circulating pressure at the point the branch leaves the lateral,

as the originating pressure and 1 lb. as the circulating pressure at the end of the branch. Some very interesting problems are found in this work.

The author advocates the use of pipe bends instead of elbows or fittings in the lateral lines.

There has been a practice made use of by some engineers to run a larger return line than flow line; for instance, a 3-in. flow and a 4-in. return line. This method, it is claimed, gives a more equal circulating pressure all over the pipe line system. The author has found that by limiting the heavy friction loss to the main trunk lines this objection is as equally well overcome and the investment is slightly reduced in some cases.

In designing a central station steam pipe line the same general plan is used. In this case, however, the friction loss is dependent upon the maximum back pressure allowed on the engines if connected as a by-product plant. A live steam central heating plant should be designed along the same general plan as a hot water heating system, with 25 lbs. as the maximum pressure on the pipe line. Curve Nos. 3–5 show the curves used for the steam pipe capacities. (Pp. 29, 30 and 31.)

Assuming the same territory, viz., Blocks Nos. 1 and 2, to lay out a steam heating pipe line. In this case we will also assume that the original pressure where the line begins to be 3 lbs. We will want, at least, 1 lb. pressure at the end of the line. We can, therefore, lose 2 lbs. in friction. This allows us 0.25 lb. per 100 ft. In the case of steam pipe line we have the following conditions:

First	200 ft. of line must handle	12,000	sq. ft. of radiation.
Second	200 ft. of line must handle	9,000	sq. ft. of radiation.
Third	200 ft. of line must handle	6,000	sq. ft. of radiation.
Fourth	200 ft. of line must handle	3,000	sq. ft. of radiation.

From curve No. 4 a 6-in. line will handle 12,000 sq. ft. of radiation with about this loss, a 5-in. line will handle 9,000 sq. ft., but the friction loss will be too great (0.40 lb.), therefore, we will continue the 6-in. 100 ft. beyond the first section, viz., 300 ft. in all, and the last 100 ft. we will make 5-in. From curve No. 3 a 4½-in. line will

handle the third section of 6,000 sq. ft. of radiation with approximately this friction loss, and a 4-in. will suffice for the last section handling 3,000 sq. ft., for, as in the case of hot water heating, there should be a minimum size to install as a main and in steam heating, the author has fixed upon 4-in. as a minimum. The above pipe sizes are figured with the steam and condensation going in the same direction. If going in opposite direction, a greater friction loss will be sustained.

In designing a two-pipe steam pipe line system, figure the same sized steam line as for a one-pipe system. The return line should be calculated for pump or gravity return, whichever it is. Pump return allows smaller pipe sizes. As a general rule, the return main should be one-half the diameter of the steam main. This rule, however, gives us too large a line in many cases. The following table will answer this purpose very safely:

Diameter of Steam Main, in inches.	Diameter of Return Main, in inches.
20	6
18	6
16	5
14	5
12	4
10	3
8	2½
6	2
5	1½
4	1¼

In designing a one-pipe belt system for water heating use the curves Nos. 1 and 2 and consider the friction loss ⅔ of that given by the curves and figure the entire length of each belt. This is due to the fact that the curves are made up for the design of the two-pipe multiple system and, in that system, the friction loss is figured on part of the water in the line returning before it goes the full length of the line, thus reducing the quantity carried and con-

sequently this reduces the friction loss and it also takes into consideration the two pipes, while in the belt system we have only one pipe, but all of the water goes from one end to the other. For example, from curve No. 1 a 5-in. line will handle 28,000 sq. ft. of radiation with a friction drop of 0.66 lb. per 100 ft., or 35,000 sq. ft. with a friction loss of 1 lb. per 100 ft.

The pipe sizes given here for both steam and water are conservatively large and, consequently, a little deviation from them will not be bad practice.

There are, of course, other methods of designing central station pipe lines somewhat more elaborate and a great deal more lengthy, but the method outlined is accurate for any central station lay-out, and has the advantage of being rapid as well as reliable.

The detail of the construction, such as insulation, method of handling, of expansion, anchors, taps, drainage, etc., will be considered later, although the capacity of a given sized line is seriously affected by faulty construction, and this point should be carefully considered.

Percentage of Line Loss

This term is often used to designate the line loss in a given system. It is, as a matter of fact, of little value except as a relative value. It is commonly considered to be the percentage of the amount of heat lost in the distributing system to the amount consumed in the radiation attached to the system. The only way this can be determined accurately in a steam system is to measure the condensation liberated from all radiation, and measure all condensation coming from the pipe line drains. In hot water lines, this is not possible and the line loss in hot water mains must be figured as shown before on the basis of the square feet of line surface. The experiments to determine hot water line loss can be made on any pipe line by installing a meter (venturi type) and thermometers at the beginning and end of the section of line to be tested. Knowing the number of pounds of water flowing per hour and the difference in temperature between the beginning and the end of the section, also the number of square feet

of pipe line surface, the line loss in B. T. U. can be computed from the formula:

$$\frac{W\,(t_b - t_e)}{F} = \text{line loss per square foot.}$$

where W = number of pounds water flowing per hour
t_b = temperature of water leaving test section
t_e = temperature of water entering test section
F = number of square feet of pipe line surface.

The percentage of line loss to the amount consumed is a decidedly variable quantity for the reason that the amount consumed fluctuates to such a great extent, while the line loss remains nearly constant. For example, on a mild May or September day, with nearly no steam being consumed by the connected buildings, the percentage of line loss may run as high as 300%, while on an extremely cold and windy day, with the buildings using a great amount of steam, the percentage of line loss may be as low as ½ of 1%. The average percentage of line loss should be from 5% to 10%.

Pipe line systems in central station heating are divided into two divisions, (1) steam and (2) water. These two are each again divided into two parts, one-pipe and two-pipe, according to the following:

Steam { one-pipe system.
two-pipe system.

Water { two-pipe multiple system.
one-pipe series or belt system.

The one-pipe steam system is the most commonly used. The two-pipe steam system is composed of a return main, in addition to the steam main. High or low pressure systems are the same in this connection.

The two-pipe multiple water system is composed of a flow, or outgoing, pipe and a return, or incoming, pipe. The water in this system goes out in the flow pipe to the building to be heated and then returns into the return pipe and goes back to the station to be reheated—as shown in Fig. 9.

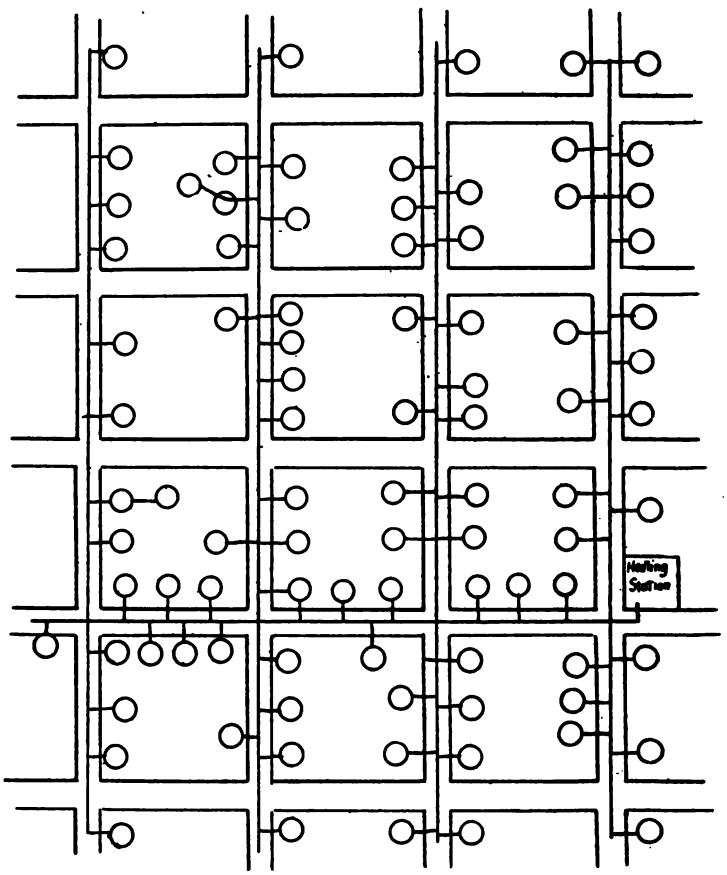

FIG. 7—ONE-PIPE STEAM SYSTEM

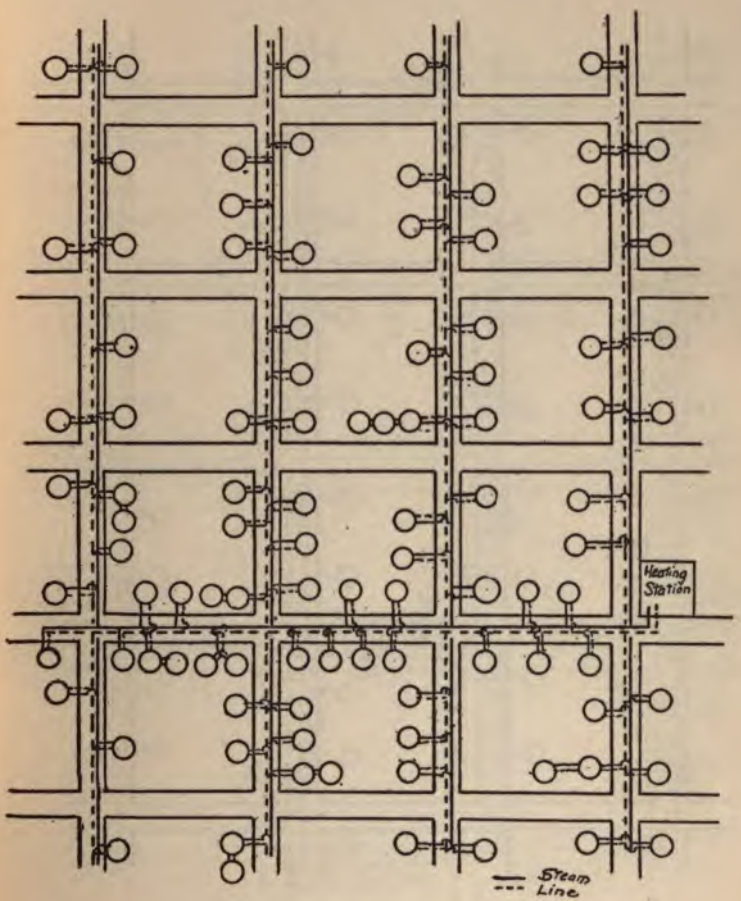

FIG. 8—TWO-PIPE STEAM SYSTEM

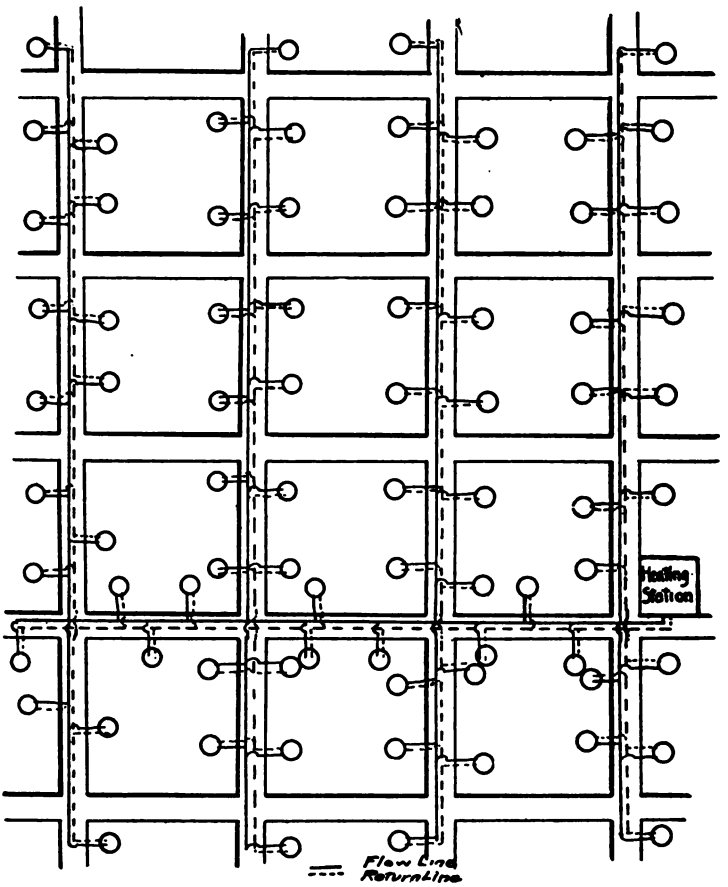

FIG. 9—MULTIPLE SYSTEM, WATER

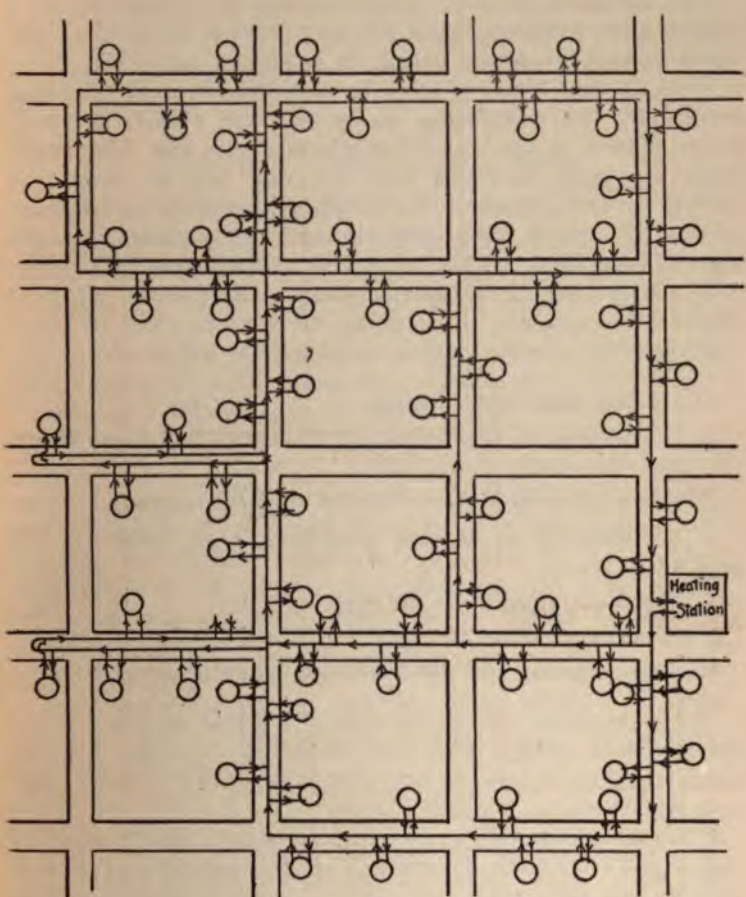

FIG. 10—BELT SYSTEM, WATER

The system operates due to the difference in pressure in the flow and return pipe, caused by the circulating pump at the station.

The one-pipe, or belt water system is composed of a belt of pipe feeding direct to each service, or feeding another belt or group of belts. It is shown herewith.

This system operates due to the difference in pressure caused by the circulating pump and the chokes or stoppages placed in the pipe line which divert the flow away from the main belt out into the side belt or shunt, as shown by the arrows. The services are taken off the top of the pipe where the hottest water is and returns into the side of the pipe. This allows a temperature difference which helps the circulation caused by the pump. Both of these water systems work well.

Comparing the two water systems, we have:

1. **Initial cost** about equal.
2. **Economy** of operation, as concerns line loss, about the same for each.
3. **Flexibility** is in favor of the multiple system.
4. **Uniformity** of service rendered is in favor of the multiple system.
5. **Services** smaller in multiple system.
6. **Station conditions** equal.
7. **Depreciation and Maintenance,** equal.

We note from the above that the items 3 and 4 favor the multiple system and that probably accounts for the more common use of the multiple system in extensive central station water heating plants.

Comparing the one and two-pipe steam plants (Fig. 7 and Fig. 8) we find, of course, that the one-pipe system is less, in first cost, than the two-pipe, and, if then the two-pipe system has any claim for recognition, it is that in a two-pipe system we return the condensed water to the station. When we have bad water conditions this is worth considering. The problem to be solved in deciding between a one-pipe system and a two-pipe system is to ascertain which system is the most economical in the end. To

do this, add the interest, depreciation and maintenance on the increased investment to the cost of operating the pump or pumps, if any are necessary, to return the condensed water. On the other side, figure how much can be saved by returning the water, consider the heat in the water and allow for the less frequent cleaning of boilers, also the cost of the water. With the difference in the two sums the more economical system will be found.

Tunnel and Conduit Construction

On pages 57-69 are given illustrations of some tunnels and conduits in use at the present time. It is interesting to note that many other styles and kinds have been used, but only the styles in more general use are given here. Probably more make-shift designs and foolish ideas have been employed in underground heating work than in any other branch of engineering, due, undoubtedly, to the lack of experience on the part of the designers or their desire to get something for little money. They have, however, brought out, by means of contrast, the better forms of construction and while, of course, the good underground construction costs considerable at the start, yet, in the long run, it will more than pay for itself. It is decidedly foolish economy to use inferior material or poor workmanship in anything going under ground to stay as long in service as a heating system should stay in service. It is no little matter to take up and relay a heating main after it has deteriorated, but, on the other hand, as shown under "Pipe Line Losses," in this book, it will be economy to do it nevertheless.

The best form of construction from the standpoint of easy maintenance and flexibility, as, for example, increasing the size of a line, is tunnel construction. The cost of tunnels prohibits their use in most cases. For that reason only in large plants and in plants where the expense of construction is of no consequence, can it be used. It is imperative, therefore, to find a form of conduit construction that will answer our purpose.

In selecting a conduit be sure it is durable, efficient and flexible; flexible to the extent that it can be used any-

where, that it will fit any angle or curve and can be taken up and relayed, if necessary, for it often develops that it is necessary to increase the size of a line on a certain street and the line there installed to be moved to another location; efficient as a heat insulator and durable to the extent that it will remain efficient for a good length of time. If these three characteristics are found it is safe to say that we have found a good conduit.

In this connection it might be added that it is poor practice to run electric conduits and heating conduits in the same trench and entering the same manholes. Electric conductors should be kept cool while heating pipes should be kept hot and trouble will result if they are put in the same manholes and same trench.

Expansion and Contraction.—In the tables at the end of the book will be found one giving the expansion of steel, wrought-iron and cast-iron pipe. It is probably useless to spend any time explaining why expansion devices are necessary. A heating line will not stay in the ground without them. The travel due to expansion must be controlled and, for that reason, line anchors are necessary to hold certain points stationary.

Whether the slip or disc form of expansion device be used is a matter of detail. It is probably true, however, that the slip joint is gaining in favor. Pipe bends which were used at one time are seldom used now in new construction. They add friction to the line which is not offset by their lower first cost. The disc device has many good points and so has the slip. Either will answer the purpose satisfactorily.

Pipe.—There are four kinds of pipe used in central heating:

1. Wrought steel.
2. Strictly wrought iron.
3. Cast iron.
4. Wood.

As to the most durable, as far as the material is concerned, cast iron probably heads the list, but the methods

used in connecting this kind of pipe are not particularly advantageous. Flanged connections under ground are not desirable. Lead joints will not do, under any condition, and, for that reason, cast iron is not used extensively.

As to the relative merits of steel and wrought iron pipe a whole book could be written and, after all is said, there would be no decision. For that reason only a few points will be mentioned in this connection. Many tests have been made which show the superiority of steel pipe and about the same number of tests have shown wrought iron to be the better. The fact that the author has seen steel pipe stay in the ground 10 years without any appreciable depreciation leads him to believe that steel pipe is just as good as wrought iron for almost any heating service.

There are many engineers who claim to have had much trouble with steel pipe and who would not use steel. The opinion of these men may be biased, but it is not probable. Wrought iron has been used so successfully, especially in steam heating, that, while steel may be equally as good, it is difficult to decide to make the change and run the risk. In a few years, however, after the soft steel pipe has demonstrated its ability to stand up, it will undoubtedly be accepted as the equal to wrought iron even by the most skeptical.

For water heating, steel has proven that it will fill the bill acceptably.

The wear on pipe is from the inside, and never from the outside, if the line is constructed properly, well underdrained and no leaks allowed to exist for any length of time. It is due more to the entrained air that is in the steam or water than any other one thing that any pipe pits or corrodes on the inside.

Wooden pipe is used for water heating and for return lines in two-pipe steam systems. It works out admirably well in this connection, especially if little pressure is carried on the mains. It withstands carrying condensed steam and air mixed together as well as any style of construction.

Notes on Construction of Pipe Lines

The author's experience has caused him to note here a few things that may be of interest to the construction man, especially if he is anxious to build the best possible line.

Grading.—All lines and especially steam lines should be carefully graded so that no pockets exist. Air pockets in water lines are detrimental from the fact that they cut off some of the pipe area, and water pockets in steam lines are bad for the same reason and, in addition, because they cause or are apt to cause water hammer.

Foundation.—A pipe line should be laid on a good and lasting foundation. If it is not it may sag and spoil or entirely eliminate the grade of the line.

Backfilling.—The earth that is replaced should be well tamped into place so as to eliminate any settling after the work is completed. Never use any cinders to fill the trench. The action of the sulphur in the cinders is death upon the pipe or any metal under ground.

Underdrainage.—Use special effort to see that this is carefully installed. Cover with crushed rock; avoid using cinders in this connection. Gravel is a good substitute for crushed rock, if it is coarse enough, but it should be free from loam or clay.

Expansion Joints.—See that these are in perfect alignment and that they can work easily. Keep the brasses clean and free from mortar. They should be packed evenly and firmly, but do not draw up the gland too tight.

Manholes.—Build these large and roomy and make them as water tight as possible. Hard burned brick and cement mortar should be used.

Pipe Work.—Use all possible care in putting the pipe and fittings together. If this is done, less trouble will result from the test which should be severe enough to show up any defect. It is poor practice to caulk a threaded joint to make it tight, but, sometimes, a tap or two with a ball

hammer will stop all the trouble. Use reason in the use of caulking the joints—and be absolutely sure all joints are tight before allowing them to be covered. Use a good grade of oil or graphite paint in making up the joints.

Replacing of the Pavement

In the majority of cities the pavement, when disturbed, must be replaced by the person taking it up and under the inspection and to the satisfaction of the city officials. In other cities, the city replaces the pavement and the heating company pays the city a given price per square yard. The latter arrangement is probably the easier way from the heating company's standpoint. It all depends upon how well the city's department of streets repairs the streets whether it is a better arrangement from the citizen's point of view. If the city does this work well, this arrangement is probably the better way all around. On the other hand, if the heating company must replace the pavement the city can demand a good job and get it. The main point at issue is whether or not the company doing the work wants to do good work and any utility company that is at all far-sighted will see that it is to its advantage to replace the pavement in the best manner it can possibly be done.

Nothing will give a heating company a better standing in its city, nothing will develop so many boosters as for the company to replace the pavement in a perfect condition. It is for the above reason that the company should use all possible means to put the paving back correctly.

The author's experience has been that everybody who has done any repaving has a way that he considers the best way to replace the pavement. This is especially so with city officials and in ninety-nine cases out of a hundred it is worthy of consideration, for the average layman is quick to recognize a good job and quick to discover the method employed to do the good work.

There are two main points to be considered in replacing pavement: (1) the foundation and (2) the neatness of the patch. No matter what kind of paving is to be replaced, it is essential that it be built on a good foundation. If

otherwise, it is bound to settle and cause holes and bumps. The foundation, therefore, cannot be too good. If we will remember, in addition, that the patch must be attached to the rest of the pavement so that the line of demarcation cannot be found we will, without a doubt, have accomplished a good job of repaving.

We will take up the question of the foundation first. Suppose, for example, the accompanying drawing shows a cross-section of a trench cut in a street, paved with brick,

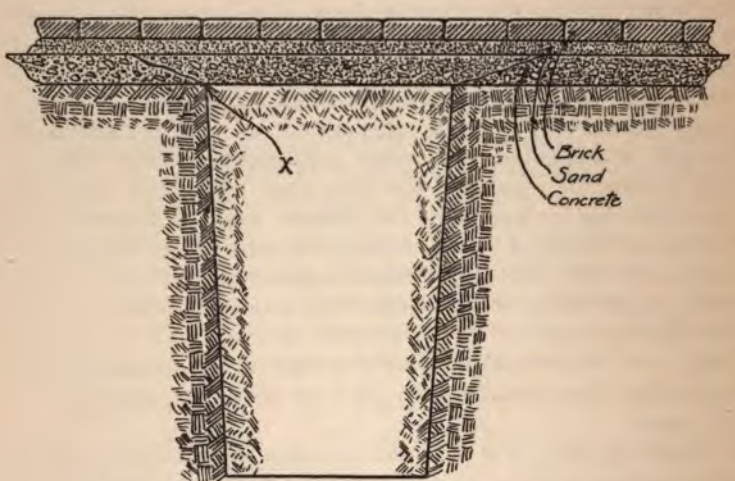

FIG. 11—CROSS-SECTION OF TRENCH CUT IN STREET

with a 1-in. sand cushion and a 5-in. concrete base. This is one of the easiest pavements to patch well. Fill up the trench to a point "X" at the bottom of the adjoining concrete base. Then proceed as follows:

On both sides of the ditch take up a strip one brick wide and clean off the concrete. Pick the concrete surface so as to cause a sloping surface as shown. Be sure this surface is clean and rough. Then put in the concrete base and create a good bond between the old base and the new. If the base is at least 5 in. thick, no reinforcement is necessary, but if not that heavy, it will be advantageous to reinforce with steel to give the necessary strength. This,

of course, depends also upon the width of the trench. Use a good mixture of concrete and let it set up well. After this is done put on the sand cushion and then the brick. In placing the brick cut out all the half bricks and fill in with full-sized, using care to see that a perfect match is made. It is sometimes necessary to use a brick a shade smaller than the original so that a good fit can be had, for it is very difficult to clean the cement off of the old bricks that have been taken up, especially if the binder concrete had been a good mixture.

If the paving to be replaced is without a concrete foundation a little different method should be used. Fill up the trench to a point about 12 in. from the street surface. Take up a strip of the brick at least 1 ft. wide on either side of the trench and excavate the soil until a good firm footing is obtained. Then put in a concrete foundation of sufficient strength to support the load. Then put on the sand and brick.

What has been said in the examples given will apply equally as well to other forms of pavement, especially where the finish of the pavement is a coating, such as asphalt, bithulithic, or asphaltic concrete. Creosote or granite block pavement should be handled the same as brick.

Macadam paving is difficult to patch nicely. Care and a good road roller are the two things necessary. In the case of macadam, it is better to take up a strip of the paving on both sides of the trench before patching. This allows a better bond and it is easier to make a good job this way. The first layers of the stone should be tamped into place by hand and the finishing done by the roller.

A point that is often considered important in connection with the repaving is the filling of the trench. In the author's opinion, this is not half so important as the concrete foundation for the pavement. Do not allow any traffic on the pavement until the foundation and binder are thoroughly set. Then, if a good grade of concrete has been used and the proper footings obtained for the foundations, there is no danger of the pavement settling or becoming rough.

In the case of macadam or cobblestone pavement the filling of the trench is important and careful hand tamping is essential, because there is no concrete foundation. It is oftentimes better to put in a concrete base or foundation even under macadam or cobblestone paving.

In alley construction, especially where the allies are narrow, it is often cheaper and, of course, better to relay all the brick or block and patch only the concrete base.

It costs considerable to relay pavement properly, but it is always cheaper to do the work right in the first place and not have any bad places to fix in the future.

There is no short, quick way to replace pavement properly. It can be done only by thorough and careful work, beginning right with a good foundation.

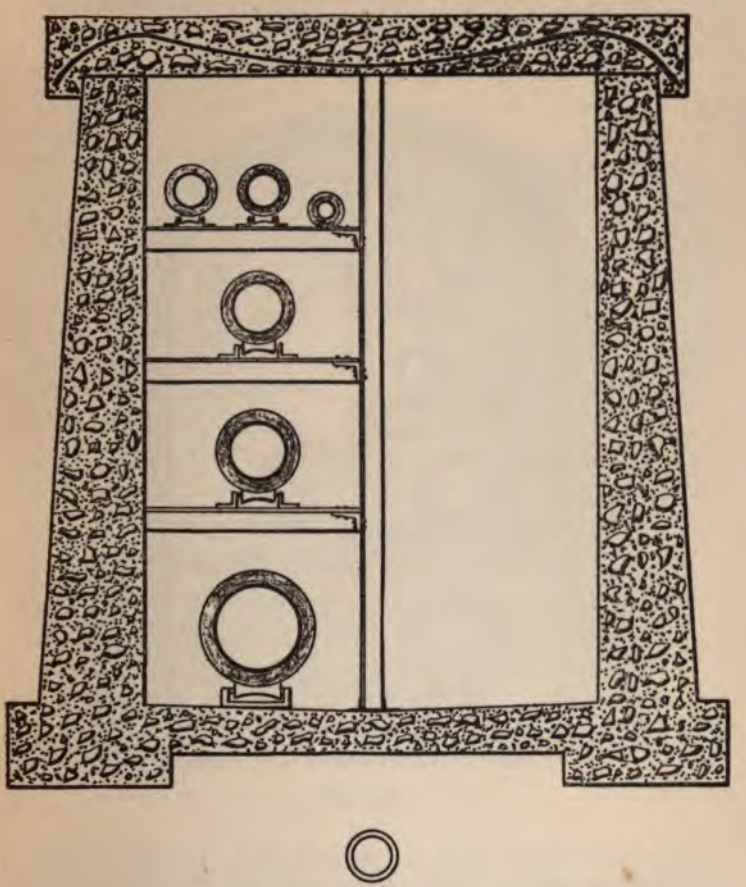

FIG. 12

This drawing shows the square or box-shaped tunnel construction, built of concrete, with reinforced concrete roof. This type offers many possibilities in arranging the pipe positions.

The details of the design, such as the thickness of the walls and top and the reinforcement required, should be worked out for each individual case. The walls can, of course, be built of brick or stone, if desirable. The tunnel should be waterproofed on the top and sides, and should be underdrained. This drawing shows the underdrain under the center of the tunnel. This is not as good a location for the underdrain as shown in the next figure.

The supports shown here are angle irons. Other designs can be adopted to suit the idea of the designer.

The floor of the tunnel should drain to a sewer connection, sump or drain-pit, and be kept as dry as possible.

This arrangement shows a low-pressure steam pipe, two hot water pipes, two ammonia pipes and one compressed air line. The dimensions are 7 ft. high by 5 ft. wide, inside.

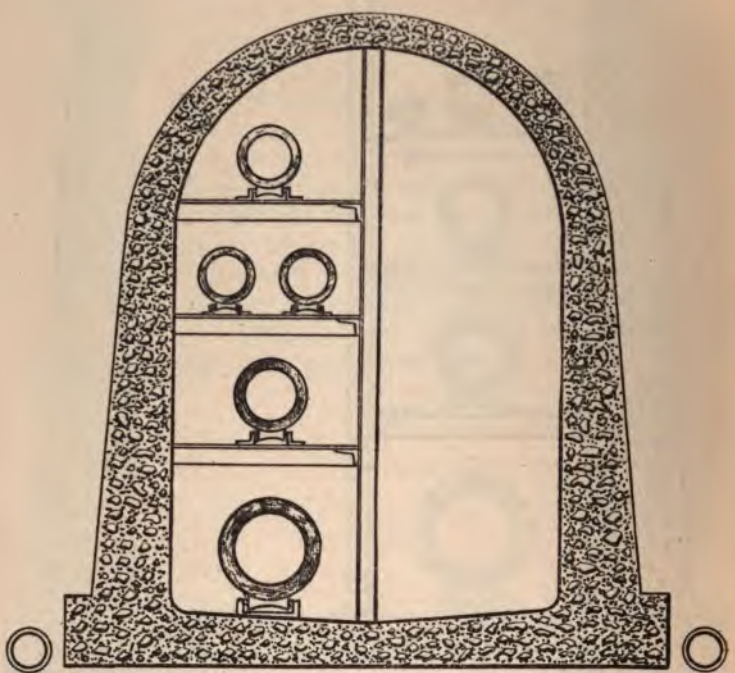

FIG. 13

This tunnel construction is the arch type. It can be built of reinforced concrete or brick, and is a very easy tunnel to build with collapsible forms. The underdrainage is located on either side. This requires a somewhat wider trench, but is more efficient installed this way. Any arrangement of piping can be secured that is desired. The usual floor drainage should be provided and waterproofing of the tunnel is necessary.

Angle iron supports are shown here, but bar iron, channel iron or I-beam supports can be used.

As a rule, the passageway should be, at least, 2 ft. wide in the clear, and it is better to make it 30 in.

Manhole openings should be made in any tunnel system, if it is not self-ventilating, and heating tunnels should not be self-ventilating, for it increases the heat loss in the mains. An electric fan, which can be attached to the lighting circuit necessary in every tunnel, will, in conjunction with two manhole openings, give sufficient ventilation for the men working in the tunnel on any repair work.

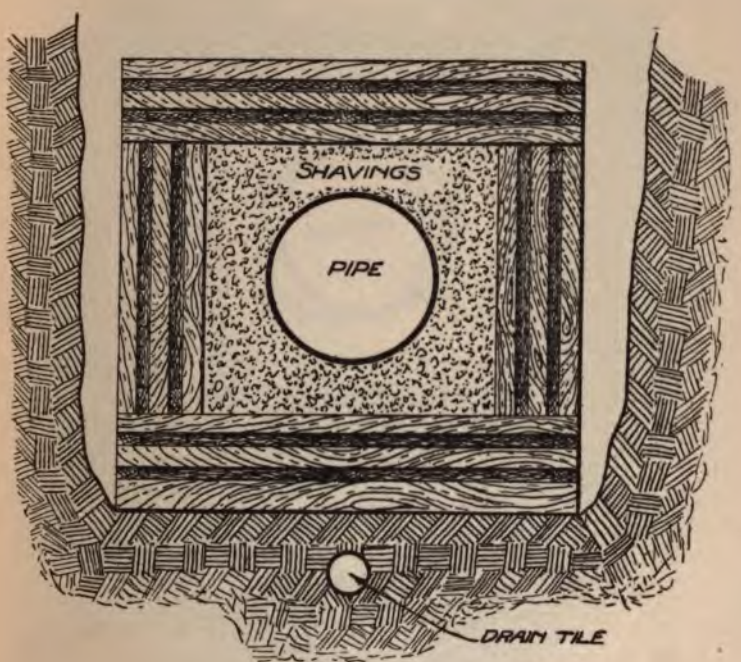

FIG. 14

This drawing shows a wooden box conduit, built up of three 1-in. thicknesses of hemlock or cypress lumber. The air spaces are filled with hair felt or building paper. The pipe is covered with a thin asbestos covering to protect the shavings from charring when used for steam. The shavings are sometimes treated with oil or creosote.

This conduit is very efficient as long as it has not deteriorated. It is not durable and will deteriorate rapidly. The rapidity of decay of the wood depends upon the soil in which the conduit is laid. Alternate stages or wet and dry conditions have a decidedly bad effect.

The underdrainage here shown is very bad. If the soil is not porous (when no underdrain is necessary) it will hold back all water that should drain away, and the drain will do no good at all. This is a very common fault that the author has found many times in taking up this style of conduit to replace it with new conduit. The correct method of underdrainage is shown in another drawing.

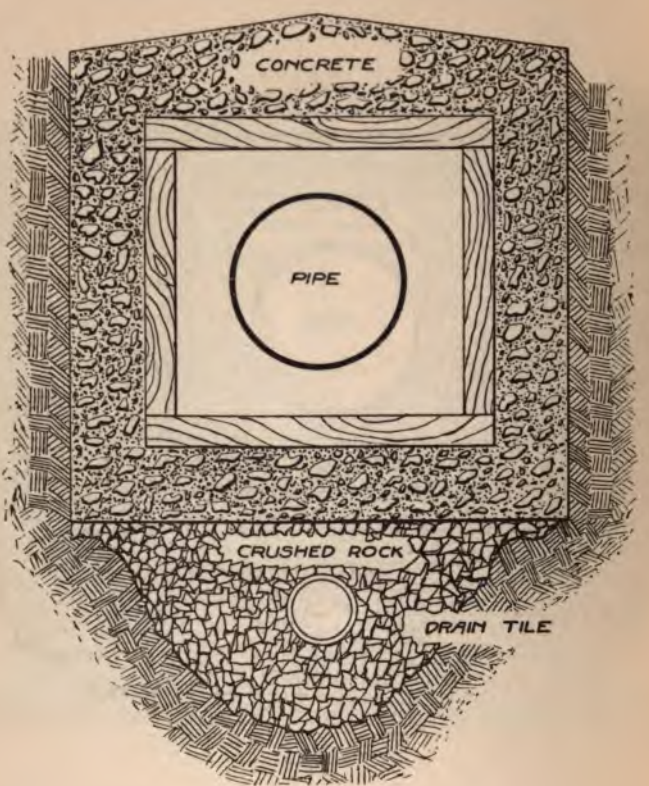

FIG. 15

This concrete box conduit has been used to a considerable extent with more or less satisfactory results. It is durable and, if waterproofed thoroughly, makes a good protection for the covering or filling around the pipe. Any covering or filling can be used that is wanted. The efficiency of the construction depends upon this covering. Concrete is not a good insulator of heat, and absorbs much moisture unless it is perfectly waterproofed. The wooden box inside the concrete is simply a form.

The system of underdrain here shown is not particularly good. The ditch should be wider and the crushed stone carried on up to the top of the box.

This construction is flexible as far as being adapted to any bends or angles necessitated by underground obstacles, but cannot be taken up and removed.

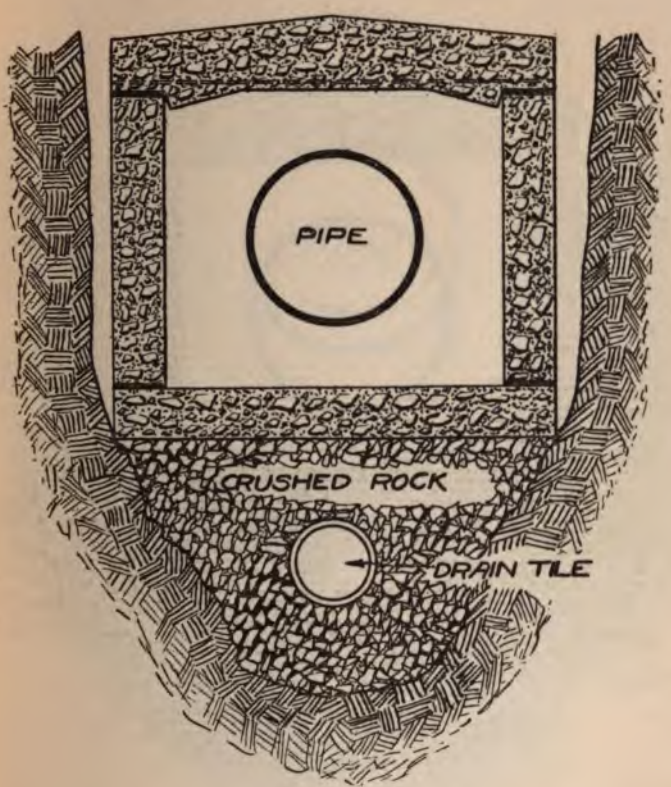

FIG. 16

This concrete block conduit has been used to some extent, and, while it is not much better than the concrete box conduit, except that it can be built faster and is a little less expensive to install, yet it has never been very popular.

Any covering can be used that is desired. The covering should be waterproofed.

This construction is flexible and can be taken up and removed, if care is taken in taking it up.

The same fault is shown here in the underdrain as is shown in the concrete box construction.

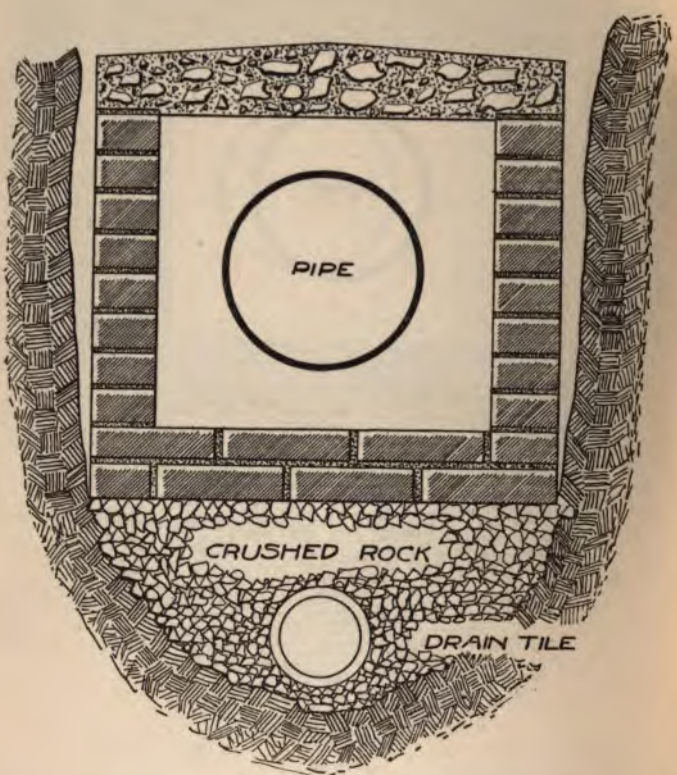

FIG. 17

This conduit, built of a brick bottom and sides, with a concrete top, has been used but little.

It is very similar to the last two conduits shown. It is included here simply because it has been used and is of interest only for that reason. There are no special features embodied in it.

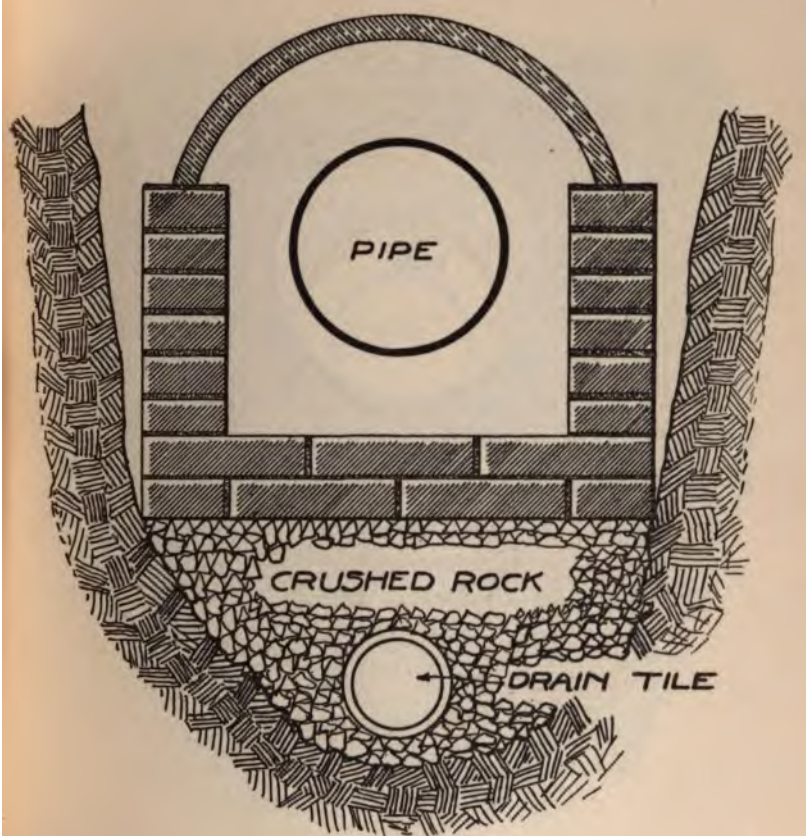

FIG. 18

This is another form of conduit sometimes used. It is made with brick sides and bottom, with hard-burned salt-glazed tile top. It is somewhat less expensive than the preceding construction, less brick being necessary. The top is waterproof, which is a feature it has which is an advantage. This construction can be taken up and relaid, but it is not easily done. It is durable. Its efficiency is dependent upon the covering used. The covering used in this conduit should be waterproofed.

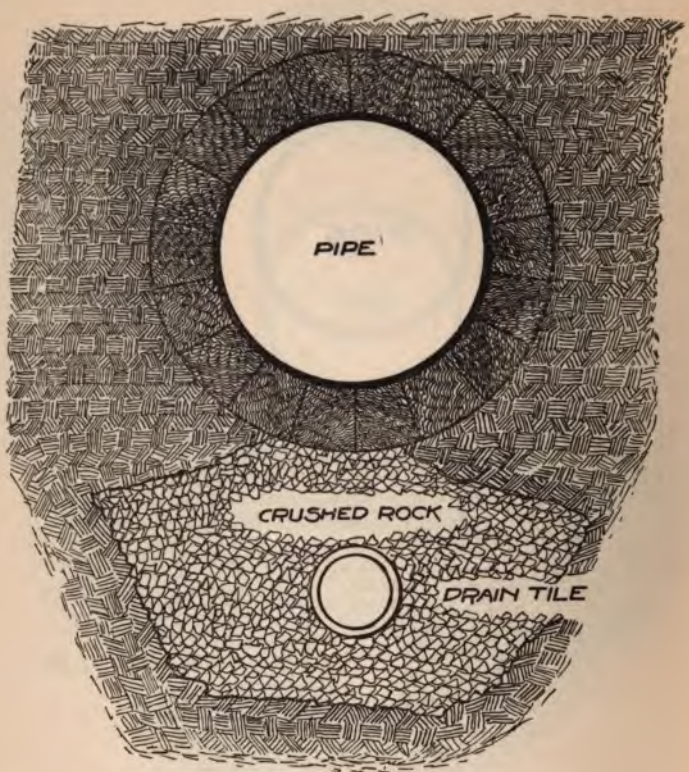

FIG. 19

This construction is cast-iron pipe covered with magnesia blocks. Its efficiency depends upon the thickness of the covering. This construction is said to be very durable, but it is difficult to take it up and relay it. The outside of the covering should be thoroughly waterproofed.

The underdrainage here shown is effective. The crushed rock furnishes a poor foundation for the line.

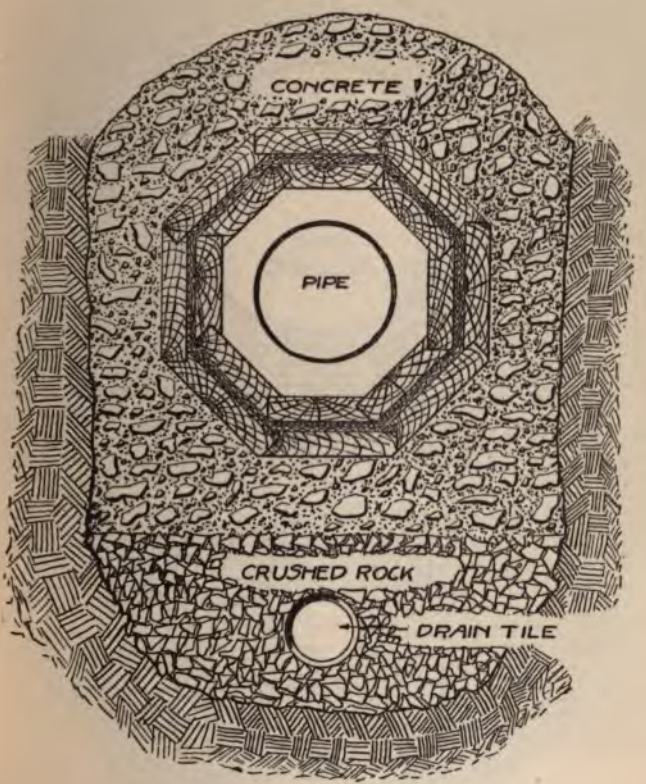

FIG. 20

This shows a well-known covering with a concrete envelope. It is durable and efficient, but difficult to take up and almost impossible to relay. It is not easily fitted around bends and angles, and these must be covered with brick or tile manholes or boxes.

This style of construction does not allow easy access to leaks, and the line for that reason should be carefully tested.

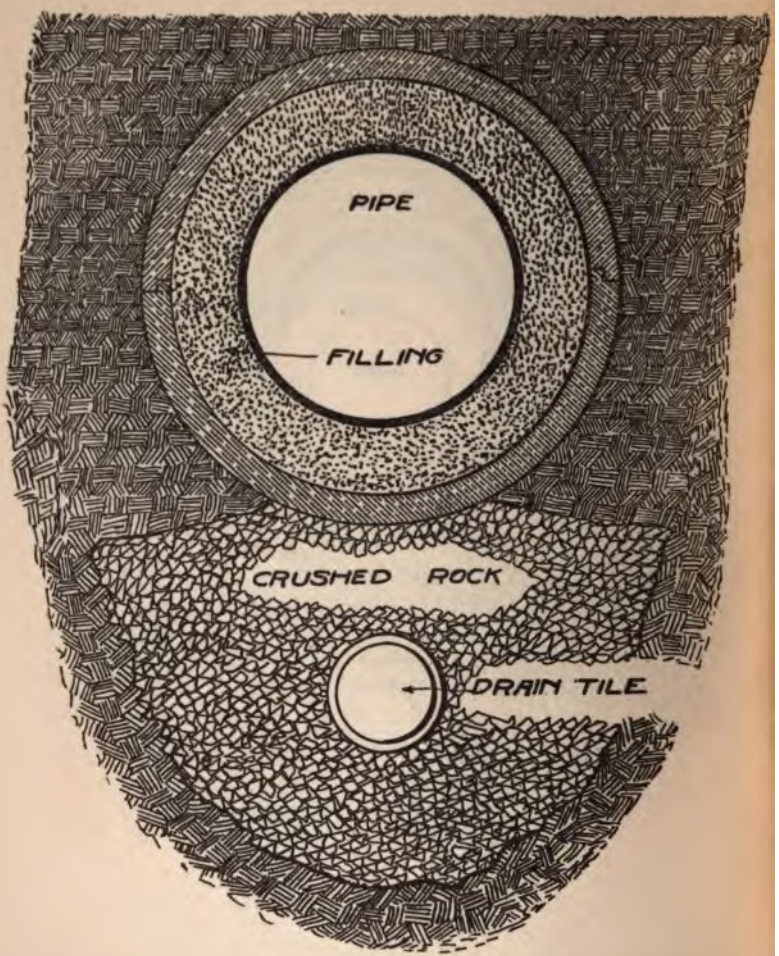

FIG. 21

This construction is composed of a split, salt-glazed clay tile. The covering is a fibrous filling. This construction is durable and efficient, but is not easily installed around short-radius bends. Angles can be covered by means of elbows of the tile.

Concrete tile, waterproofed, is sometimes used instead of salt-glazed clay tile. Sectional covering may be substituted for the filling, and should be waterproofed. The joints in the tile must be water-tight.

The underdrainage should be effective. The method shown here is good, but it would probably be better to fill in with crushed stone up to the top of the tile.

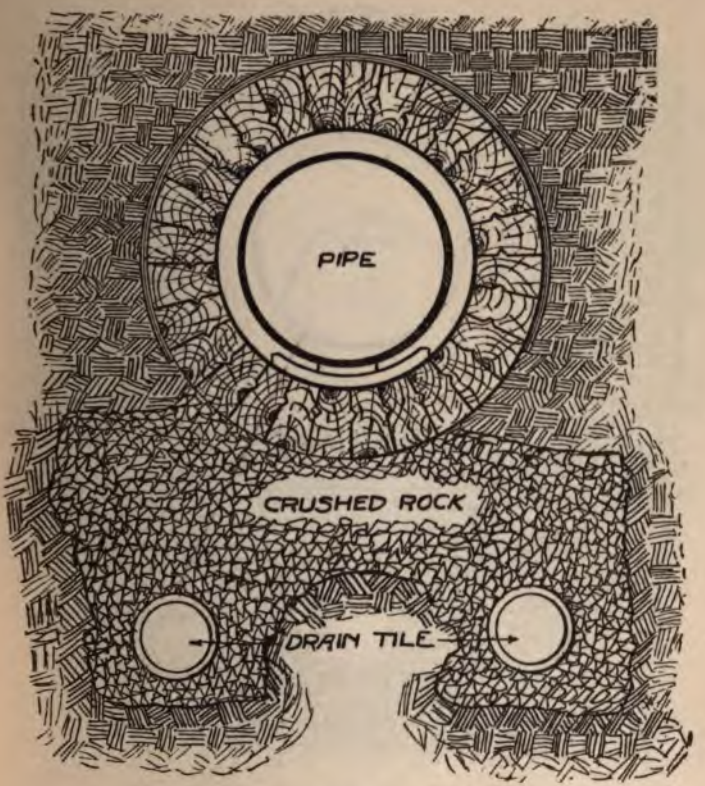

FIG. 22

This well-known construction has been used for many years. The covering is composed of selected pine staves bound together with heavy steel wire and covered with waterproofing. The sections of the covering fit together with a tongue and groove.

This covering is durable, if well underdrained, and is efficient as an insulator. It can be taken up and removed, but does not fit bends or curves. All specials and fittings must be covered with a brick or tile manhole or box.

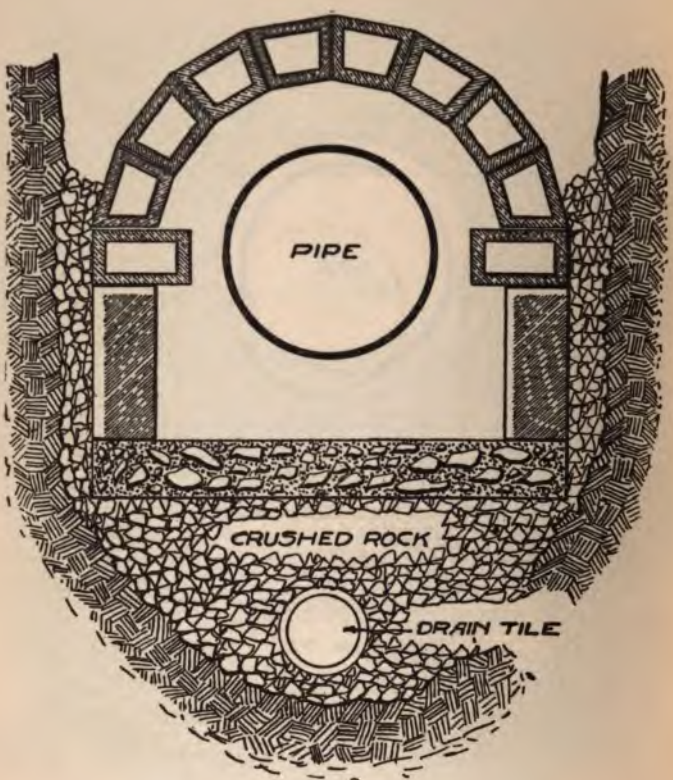

FIG. 23

This construction is designed for large pipe lines, from 20 in. to 36 in. It is a hollow tile conduit put together with cement mortar. Any covering can be used, but it should be waterproofed.

The underdrainage here shown is very effective and a very good method. The air spaces in the tile make the conduit something of an insulator. The concrete base furnishes a good foundation for the line.

The conduit is durable and efficient. It can be taken up and removed. It will fit any curve or angle and can be called flexible for that reason.

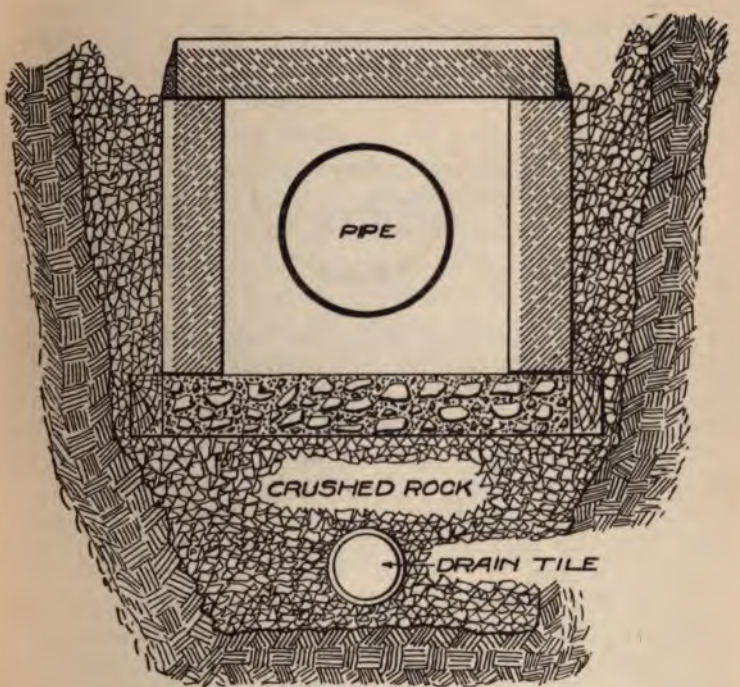

FIG. 24

This hollow tile construction is very much like the preceding. The air spaces in the tile act as an insulator, in addition to the covering. The covering used, whatever it is, should be waterproofed.

This conduit is durable and efficient as an insulator. It will fit any angle or curve.

This shows the best underdrainage method in use to-day.

CHAPTER IV

Rates

IT is this subject that affects the income of the heating plant, but the income is not directly proportional to the rate charged for the service, neither is it inversely proportional to the rate. In fact, the rate we want is that which will give us the largest net earning per dollar invested, and at the same time serve the greatest number of people in a community, for we must not get away from the fact that a central station heating plant is a public utility, which means a public servant.

Up to the present time public utility commissions have not handed down any noted decisions relative to central station heating rates, but it is only a matter of time before this subject will be given careful consideration by the commissions and then, if not before, the subject of rates on heating will be standardized.

What percentage of profit would be called reasonable for central station heating plants has not been definitely determined up to the present time. That it should be in excess of 6 per cent. is generally admitted because of the more or less risk that is involved in the business and, as this rate of 6 per cent. can be realized for money with practically no risk entailed in the investments, as, for example, in good mortgages and in good, well-secured bonds.

The Madison (Wis.) Gas and Electric Company was allowed 7 and a fraction per cent. on its gas investment and

8 and a fraction per cent. on its electrical investment by the Wisconsin commission. It seems, then, that 10 per cent. to 12 per cent. would be a reasonable profit for heating plants to make on their investment, after depreciation has been charged off.

There are at this time two different methods used in charging for service:

(1) Meter basis.
(2) Flat rate basis.

The flat rate basis is subdivided again into two methods:

(1) Square foot of radiation basis.
(2) Cubic foot of contents basis.

There are, of course, advocates for each method. The writer knows of one large heating company which, after being on a meter basis, took out all meters and charged on a per square foot of radiation basis, because it claimed that it took too much time and money to watch the meters and adjust the bills each month. This trouble, it seems to the author, could have been obviated by careful installation and inspection of the meters. There will be without doubt many improvements in the steam meters, or rather in the method of using them. Also, a meter will be devised that will measure hot water heating service, but at present the flat rate is the only practical rate for hot water service.

It is not the intention of the author to advocate either method, as against the other, but rather to take for granted that both have come to stay, as is undoubtedly the case, and point out wherein the net results are affected by the rate to be charged in either case.

In any steam heating franchise granted in these days, the municipality will and should demand that the rate be stated plainly, and, in such a franchise, both meter and flat rates should be given, for the benefit of the company, as well as for the benefit of the city; for the company, because at some time it might be necessary to serve consumers on either basis or both cases, and for the city, because it allows the consumer the choice of either system. The rates in this event should be equally equitable to both the consumer and the company.

Some consumers would rather pay more money per year, and know what they are to pay, than to be disappointed each month with a bill that they will invariably think is too high, and, on the other hand, there will be many consumers who will want the meter basis so that they can save money. Under any condition the consumer must be satisfied, and both methods are, therefore, advisable.

In a hot water heating franchise the meter rate is not necessary, because there are no meters on the market. When they do come, they will probably be the heat unit meter, and in that event 1,000,000 B. T. U. would be the logical basis of charge.

On a meter basis for steam heating, 1000 lbs. of steam is the basis of charge.

On a meter basis for hot water, 1,000,000 B. T. U. will probably be the basis of charge.

On a flat rate basis for hot water or steam heating the charge per annum or per season is either per square foot of radiation or per 1000 cu. ft. of space heated.

When the charge per square foot of radiation is used as a basis it should be stated clearly that it is the radiation required to heat the building and not the radiation that is set in the building. The required radiation is the amount necessary to set so that the company can guarantee to maintain a comfortable temperature.

The rules for figuring these requirements should be plainly set out and should be rules that have been found reliable. The company should not be obliged to serve any building that is not equipped with at least the required amount of radiation. For if it did, it could not give satisfaction and that would be suicidal for the company and disagreeable to everyone concerned. The question has been asked many times, "Why do you require that I set a radiator in the guest's bedroom? We never use it and don't want it heated. We always have the door to this room closed," etc. It is, however, very easy to open the door and "take the chill off this room," and while doing it take the heat away from the rest of the house or take the heat away from the heating company without paying for it. One is as bad as the other.

For that reason all rooms in the building should be equipped with the proper-sized radiators or, at least, the building should contain, in total, the required amount of radiation and the consumer should pay for the full requirements even though he does shut his bedroom radiator off at night, for in the morning, when he turns it on, he demands the capacity at the plant and in the mains to furnish that heat, and the company is reserving capacity in its mains and in its station to take care of him at all times. In other words, he demands a certain service that must be in reserve for him and for that reason he should not object to pay for it at a reasonable price.

With the flat rate per square foot basis, thermostatic control is almost essential to good operation and economical use of heat in the residences and buildings. With its use a more even distribution of heat is obtained over the entire heating system and an even temperature will be assured to all consumers. This device also saves the waste of heat and allows a lower rate to be charged for what is better service. There is, therefore, a two-fold advantage in using thermostatic control, and it accrues to the interest of the consumer as well as to the company, on a flat rate basis.

The flat rate basis charge, of so much per thousand cubic feet of space, is not as equitable as the per square foot of radiation basis. For each and every 1000 cu. ft. of contents do not require the same amount of heat, owing to the difference in location and difference in use. For instance, 1000 cu. ft. in a corner drug store requires more heat at zero outside than does 1000 cu. ft. in a dentist's office at zero outside. This method is not used very much at the present time.

Meter rates should be based either on what it actually costs to give the service, plus a profit which is fair and equitable, or, if this information is not available, the rates can be based upon data from other towns of similar conditions, relative to outside temperature, price of fuel, cost of construction, etc. Under any condition, the company or the city, if a franchise is being granted, could afford to consult a central station heating engineer and get his report on the proposition.

Fifty cents per thousand pounds of steam condensed is approximately equal to fifty cents per 1,000,000 B. T. U., assuming 1 lb. of steam to liberate 1000 B. T. U., when condensing in a heating system.

The cost to the company to give heating service is made up of the following items, which should be figured on a basis of 1000 lbs. of steam generated or a multiple of that quantity.

Generating cost.	Taxes and insurance. Fuel. Water. Supplies. Repairs and renewals. Labor. Depreciation based on cost of generating station and machinery.
Distribution cost.	Taxes and insurance. Line loss in pounds of steam. Labor. Repairs and renewals. Depreciation based on cost of distributing system.
General, pro rated into above two.	Management, general expenses, and fixed charges.

In figuring on a new plant these costs should be figured for the conditions under consideration and a careful study of these conditions should be made.

The cost of hot water heat is computed the same way as for steam except the basis of figuring is per 1,000,000 B. T. U. generated.

The flat rate charged for steam or hot water per square foot of radiation per season is based upon the average number of heat units given off by the radiation, plus that given off by the pipe line, plus that given off by the piping in the buildings, which is approximately 5 per cent. in the first case, in a well constructed pipe line, and 5 per cent. in the second case, if the pipes are covered.

Take, for example, a city with an average temperature of 40° F. during the heating season. Average temperature of building = 70° F. Average temperature of circulating water in radiator (average wind), 140° (180° schedule);

difference in temperature between room and radiator, 70° F.—B. T. U. emitted per square foot per hour = 1.65 x 70 = 115.5 B. T. U. plus 10 per cent. (5 + 5) for line and piping loss = 127 B. T. U. per hour.

A heating season from October 1 to May 15 is equal to 227 days or 5548 hrs. 5548 hrs. is the total number of hours in the average heating season, but there are about 350 hrs. during the average season that heat is not needed, and for that reason 5200 hrs. can be considered as the average heating hours in a season.

5200 × 127 = 660,400 B. T. U. per season, including line and piping loss.

5200 × 121.2 = 630,300 B.T.U. per season used in a building, provided each square foot of radiation is so set and figured as to emit an average of 121.2 B. T. U. per hour.

Now we can see that the cost of this service depends entirely, if on the flat rate basis, upon the number of B. T. U. emitted by the radiator per hour. There is another feature that enters into this calculation that materially affects the results. The amount of heat given off by the radiator is directly proportional to the amount needed to heat the room or building in which it is placed, provided, of course, that thermostatic control is used, for when the room is up to its required temperature the supply of heat will be shut off and the heat unit consumption reduced. To check this yearly B. T. U. consumption assume a 10-room house with each room the same as shown on page 142.

B. T. U. required per hour =

Cubic contents = $\frac{10 \times 10 \times 10 \times 30}{50}$ = 600

Glass surface = 2 (3 × 6) × 34 = 1224

Exposed wall surface = ((20 × 10) —36) × 9 = 1476

3200 B. T. U.

Exposure 320

3520 B. T. U.

Radiation required for this room for —10° F. would be in C. S. hot water 60 sq. ft. and assuming 115.5 B. T. U. per square foot per hour we would have a B.T.U. consumption of 6900, which shows that about 50 per cent. of the time, at a temperature outside of 40° F., the radiator would be shut off, if thermostatic control is used.

5200 (hours) × 3520 B. T. U., 60 sq. ft. radiation = 304,720 B. T. U. per sq. ft. per season.

At the rate of 50c. per 1,000,000 B. T. U. the consumption would cost about 15.25c. plus 5 per cent. piping loss or about 16c. per square foot.

It should not be considered that thermostatic control will save 50 per cent. of the average heat consumption, for it will not, due to the fact that the consumer will shut off the radiators part of the time if the temperature of the building gets too high and, on the other hand, the occupants will demand fresh air, even with thermostatic control, and will open the window. About 30 per cent., the author believes, can be saved this way and, in addition, a more even and delightful service can be rendered to the consumer. In addition, therefore, to the above 16c. we must add about 40 per cent. or about 6c., which will bring our cost to the consumer up to 22c. per foot per season, if we assume the selling price to be equal to 50c. per 1,000,000 B. T. U., and this price has been assumed here only for comparison and not as any standard.

The Wisconsin Railroad Commission, in its reports, Vol. 2, page 302, states that, with coal at $2.00 per ton, exhaust steam could be sold at 50c. per 1000 pounds safely; that is, with a secure profit, but it also states that where live steam is sold there would be small profits unless large quantities of steam were sold.

Whether on a flat rate or a meter rate, the amount of radiation set and the amount required are important for the management of a heating plant to know and a record of this data should be kept on file in the office of the company.

In making a rate for service per season it is desirable to know the percentage of heat used in any one month during the heating season for two reasons: First, the collections

are often made monthly; second, it sometimes happens that a credit or debit is given for certain months during the season, when the service is started or stopped in mid-season. The following table will be useful in this connection:

Heat Consumption Table

Heat used up to Oct. 31	6%
From Oct. 31 to Nov. 30	12%
From Nov. 30 to Dec. 31	18%
From Dec. 31 to Jan. 31	21%
From Jan. 31 to Feb. 28	19%
From Feb. 28 to March 31	13%
From March 31 to April 30	8%
From April 30 to May 15	3%
	100%

The following division is used extensively in flat rate contracts and is easily remembered by the consumers:

5% of contract price payable October 1.
15% of contract price payable November 1.
20% of contract price payable December 1.
20% of contract price payable January 1.
20% of contract price payable February 1.
15% of contract price payable March 1.
5% of contract price payable April 1.

This gives the heating company its money partially in advance, but is no hardship to the consumer, because, as a rule, if he operates his own furnace or boiler, he buys his coal in the summer and pays for it long before he uses it; therefore, paying on the above schedule allows him to pay his heating bill in several installments during the season.

It is often necessary to pro rate a heating bill, and for that the following table has been made from the above heat consumption table:

Table of Heat Consumption for Pro-Rating Heating Charges on Flat Rate

Assuming Oct. 1 as the start of the season.
Assuming May 25 as the close of the season.
For each day in October 6/31% = 0.194%

For each day in November	12/30% = 0. 40%
For each day in December	18/31% = 0. 58%
For each day in January	21/31% = 0.677%
For each day in February	19/28% = 0.678%
For each day in March	13/31% = 0.417%
For each day in April	8/30% = 0.267%
For each day in May	3/25% = 0. 20%

As an example, assume that a building requiring 1000 sq. ft. of steam radiation at 40c. per square foot per season was connected November 21. What will the bill be for heating on the 30th of November and for the balance of the season? From the table we find that 0.4% is the proportion of the annual charge for each day in November. For nine days in November the bill would be $9 \times 0.4 = 3.6\%$ of $\$400.00 = \$14.40$. For the balance of the season the bill would be 82% of $\$400.00 = \$328.00$ plus $\$14.40 = \$342.40$.

After a building is once connected for a season it is bad policy for the heating company to allow a consumer to discontinue the service for a short time with a full rebate, because of the fact that the company has invested its capital in the service lines and mains to serve this consumer and the company must also reserve capacity in its mains and station to serve this consumer, when he again wants the service. This is often asked of a heating company when a consumer is going away for a month or six weeks. If the consumer is on a meter basis this condition can be handled by means of a minimum charge, but on the flat rate basis the better and more equitable thing to do is to disconnect 50 per cent. of the radiation and charge full rate for the remaining 50 per cent.. If the consumer is wise he will leave his house heated thoroughly while away, because of the fact that less damage will be done to the plumbing if the house is heated in cold weather and his furniture and woodwork will be better preserved in an even temperature.

Assume, now, that on February 17 the building above mentioned was to be closed up and approximately 50 per cent. of the radiation disconnected, leaving 560 sq. ft. connected. This condition continued until April 10, when the owner returned and all radiation was again connected. What credit should be allowed?

Answer:

560 feet × 40 = $224.00 per year.

From table:

11 days in February	= 11 × 0.678% =	7.458%
31 days in March	= 31 × 0.417% =	13.000%
10 days in April	= 10 × 0.267% =	2.67 %
Percentage of season that the credit is allowed on		23.128%
23.128% of $400.00		= $92.51
23.128% of 224.00		= 51.80
		$40.71

The author advises that never more than 50 per cent. of the radiation be disconnected and, whenever any radiation is disconnected, the heating guarantee should be discontinued by the heating company.

"Ready to Serve" or "Maximum Demand" Rate

This method of charge is finding universal favor in connection with public utility service, and is, without a doubt, the most scientific of any method of charge. It is based upon the exact cost of giving service, plus an equitable profit, and the consumer pays for the service in exact proportion to the service he receives.

It has often been said that a public service company should have but one rate to each and every one of its consumers, and from this principle the flat-rate charge was established. The first flat-rate method of charge was based on the cubic foot of contents of the building as a unit. It soon developed that this was not an equitable basis and it was then modified by making different rates for buildings used for different purposes.

The next step toward equitable rates was the charge based on the square foot of radiation as a unit, under the assumption that each square foot of radiation would give off the same number of heat units, but it developed that this assumption is not true, because under different conditions a square foot of radiation will give off a decidedly different number of heat

units per square foot, ranging from 300,000 B. T. U. per season to 1,400,000 B. T. U. per season. This method was somewhat improved by charging a given price per square foot of radiation required and used in connection with thermostatic control to regulate the temperature of the buildings heated. This arrangement works out admirably except that it is apt to develop a tendency of carelessness in the consumer, as any flat rate is apt to do.

The meter basis of charge has been instituted and the charge based on the heat consumed, with the condensed steam used as a basis of charge and with 1000 lbs. of condensed steam as a unit. This method of charge seemed for a time to fill the place of an equitable rate, especially with the sliding scale of prices per 1000 lbs., but this method has developed its faults also.

For example: assume a building that uses heat only six hours out of the twenty-four hours in a day. This building demands a place on the line and requires the capacity, both in the mains and at the heating station, to supply its maximum demand. The heating company must be ready to serve this building at any time it requires service. In return for that required condition, the heating company only receives pay for six hours' service, while the building using heat for eighteen hours pays the company three times the revenue paid by the other building.

It is also the case with churches or auditoriums where heat is used only two or three days out of the week. The heating company must reserve capacities for these buildings, but in return only receives about one-sixth the revenue it would receive from other buildings requiring the capacities that these churches, etc., require. It is obvious, therefore, that a rate based on the number of pounds of steam condensed is far from equitable.

It is here that the "maximum demand" or "ready to serve" rate shows its strong points as an equitable rate. As stated before, this rate is based on the cost of the service to the utility, plus an equitable profit.

We will take for granted that it costs $200,000 to install a non-byproduct heating plant to serve a given territory. In this territory there is available business amounting to 20,000,-

000 cu. ft. of space, which, for steam heating, will require approximately 200,000 sq. ft. of radiation.

The cost of operating this system is divided into two parts: (1) Fixed charges, such as interest, depreciation, distribution costs and mantenance; (2) generating costs, such as coal, water, power-house labor, and other items that vary with the amount of steam generated.

The generating costs in the plant would probably be as shown below, but this item would change materially, depending upon the cost of fuel, labor and water. We will, however, assume values here so as to more clearly explain the example.

With 200,000 sq. ft. of radiation connected, averaging 600 lbs. of steam per square foot per season, we would have 120,000,000 lbs. of steam to generate. We can also assume 1 lb. of coal will evaporate 5 lbs. of water into steam, and that this coal will cost $2.00 per ton on the plant's siding:

Coal

120,000,000 lbs. ÷ 5 = 24,000,000 lbs. coal.

12,000 tons coal @ $2.00 = $24,000.00 = 20c per 1000 lbs. steam.

Labor

The labor in this plant would cost about as follows:

1 Chief Engineer	$1,200.00
1 Assistant Engineer	900.00
6 Firemen (9 months)	3,240.00
	$5,340.00 = 4.5c per 1000 lbs. steam.

General Expense

Repairs, renewals and supplies	$600.00
One-half office expenses	1,460.00
One-half incidental expenses	500.00
	$2,560.00

Water

Water @ 5c per 1000 gals. (15,00,000) = $750.00.

Recapitulation of Generating Costs

Coal	$24,000.00
Labor	5,340.00
General expense	2,560.00
Water	750.00
	$32,650.00 = 27c per 1000 lbs. steam generated.

The fixed charges on a plant of this kind would be approximately as follows:

Interest—	
6% on $200,000.00	$12,000.00
Taxes and Insurance—	
1½% on $200,000.00	3,000.00
Depreciation—	
3% on $200,000.00	6,000.00
Maintenance—	
Estimated	1,000.00
Distribution Costs—	
One-half office expense	1,460.00
Officers' salaries	5,400,00
One-half incidental expenses	500.00
Line loss	4,334.00
	$33,694.00

The line loss is figured at the rate of 0.050 lb. steam per square foot of pipe-line surface, per hour, based upon the following line:

Diameter in inches.	Sq. ft. of surface in the pipe line and fittings.
16	7,961
12	11,700
10	14,612
8	11,070
6	10,847
5	2,482
4	3,068
	61,740

61,740 × 0.050 = 3087 lbs. steam per hour.

5,200 hours = 16,052,400 lbs. @ 27c per 1000 lbs. = $4,334.00.

With a fixed charge of $33,694.00 per season to distribute heat to 200,000 sq. ft. of radiation it is seen that it costs 16.84c per square foot to distribute the heat. We have also determined that it costs, under the assumed conditions, 27c to generate 1000 lbs. of steam. We know now what our costs are and in order to determine our selling rate we must add our profit, which should be reasonable.

It is generally conceded that 10% is an equitable income on the money invested, and, that being the case, we have 4% on $200,000.00 to add as profit (6% has already been accounted for under interest). 4% on $200,000 = $8,000.00. This item can be charged, either all to fixed charges or one-half to fixed charges and one-half to generating. The author prefers the latter scheme.

This profit added brings our fixed or service charge up to $37,694.00 per season, and this is equal to 18.84c or 19c per square foot per season. Our rate for steam used would also be increased to $36,650.00 for 120,000,000 lbs., which equals 30½c per 1000 lbs.

Under the conditions above noted, a non-byproduct plant should charge a service rate of 19c per square foot and a meter rate of at least 30c per 1000 lbs. of condensation.

In a byproduct plant the rate to be charged is figured the same way as the above.

The service charge should be paid by the consumer as any flat rate is paid, in installments either monthly or quarterly.

CHAPTER V

Heating Station

THIS is where the heat is generated. Economy and capacity are the two attributes essential to good operation. We must have sufficient capacity in the station to generate all the heat we need and the apparatus should be so arranged as to generate this heat economically.

In this chapter only those principles that have to do strictly with central heating will be considered. There are many things, such as the burning of fuel, treatment of water, handling of coal and ash, etc., that are, of course, of interest in central heating, but to treat them properly is outside of the scope of this book and the reader is advised to get this information from other sources—for it is important that these subjects be well understood by any central station heating engineer.

In the heating station we have the same general subdivision in our subject, (1) steam and (2) water. Steam systems divided into (a) vacuum and (b) pressure, and water systems are divided into (a) open and (b) closed systems.

Steam Systems.—*The Vacuum System* has a low pressure on the steam main and a vacuum or suction on the return main. Pumps are used to create the vacuum and thereby to cause the return water to come back to the plant.

Its operation is as follows: The steam is generated in the boiler and passes either through the engines after the

oil is extracted, or direct to the pipe line. Through the pipe line it goes to the buildings. It is there condensed and the condensation returns to the plant via the return line and is usually emptied into a storage tank. Here it is stored until the boilers need it. It passes from the tank to the feed water heater, then through the economizer, if one is used, and then into the boiler again.

The Pressure System is like the above except that there is no return and, consequently, no vacuum pump. The pressure carried on this system is optional with the designer, but better practice seems to be to keep the pressure as low as possible, especially if the engines exhaust into the heating mains. Some engineers design, in straight-fuel-burning plants, high pressure systems and reduce the pressure at the service of each building or in the high pressure feeder lines, but this practice has never been very popular and its advantages have never been proven. The modern practice seems to be a low-pressure system (3 to 10 lbs.) with high pressure feeders to be used as such only when necessary.

The operation of a pressure system is very simple. The steam is generated in the boilers and goes from there to the engines, and then to the pipe line, if an exhaust steam plant. If not, the steam goes direct to the pipe line and through the pipe line to the buildings. Here it is condensed and the condensed water cooled as much as possible and then dumped into the sewer.

The pressure system is used more extensively than the vacuum system.

The vacuum system allows a somewhat lower pressure on the engines and also furnishes the return water for reuse, which is a benefit sometimes.

Water Systems.—*The Open System* of hot water heating gets its name from the fact that the system is open to the atmosphere at one point. In this system we find the open heater or com-mingler used. The operation is as follows: The water returns from the pipe line and passes through a relief valve to the open heater or com-mingler where it is reheated to as high a degree as there is exhaust or live

steam to heat it. It then goes through the circulating pump and is forced, if sufficiently heated, out into the line again. If not sufficiently hot it is forced through a closed high-pressure condenser or heater, or through a circulating boiler where it is reheated more, before going out into the pipe line and to the buildings. After it goes through the buildings it returns to the plant again.

In this system the steam and circulating water mix in the open heater or the com-mingler and water is, therefore, added to the system. Consequently, it is necessary to supply some means of relief which is done by placing a relief valve on the return line; when the pressure exceeds a certain point, which it will do if water is added, the valve will open and discharge into the storage tank. This can also be accomplished by floating the storage tank on the return line and letting the overflow go direct to the tank, but this arrangement does not allow any appreciable change in the return pressure, which change is sometimes desirable.

The advantage of this system is that all the heat in the steam is transferred into the circulating water, thus giving us a high efficiency in the transmission of the heat, but it requires more energy in the pumping of the water due to the reduction in the pressure which is necessary in order to mix the steam and water and liberate the air.

Liberating or extracting the air is simple in an open heater because the pressure on the heater is the same as the atmosphere and a vent open to the air will carry off the air. In a com-mingler where from 3 in. to 16 in. of vacuum is maintained on the exhaust steam line it is not so simple, but this can be accomplished by means of tanks which work very well.

The difference in operation between a com-mingler and an open heater is that the com-mingler will create a vacuum on the engine exhaust and the open heater will not. However, the com-mingler will operate at atmosphere pressure if it is desired.

The open system throws all the condensed steam into the heating mains, which is an advantage in one way, in that it keeps the heating mains full of good water and

is a disadvantage in that it takes this water away from the boiler. But with a tight pipe line the water discharged from the overflow of the pipe line soon becomes fairly good because all make-up water is condensation and, consequently, the water for the boilers, which should be taken from the storage tank, will soon be diluted with sufficient good water to make the feed water fairly good, so that this disadvantage is not so bad.

The Closed System of hot water heating operates as follows: The water returns to the plant and goes through the circulating pumps. In this way the pumps handle the coolest water, which is some advantage. Then it goes through the exhaust steam condenser or heater and then, if not sufficiently warm, it goes through the high-pressure steam heater or the circulating or reheater boilers. Sometimes the circulating water is forced through economizers. This is a very good arrangement. After the water is reheated sufficiently it is forced out through the pipe line through the buildings and back to the plant.

The closed system operates on less power requirements in its circulation of water. The fact that it does not mix the steam with the water insures good feed water for the boilers. The heat transmissiou of the condensers or closed heaters in this system is not as great as in the open heater or com-mingler in the open system. All water entering the system should be treated so as to take out as many of the impurities as possible and thus keep the line in good shape by only putting in good water.

Which system to adopt is a question that can be decided only after local conditions are known. It is a difficult matter sometimes to determine—and generalities in this connection are misleading. If a steam plant is decided upon, it is not difficult to figure out which system, vacuum or pressure, will be the most economical. If a water plant has been chosen, it is more difficult to decide whether an open or a closed system will be the better. If a vacuum is desired on the engines, an open system with a commingler is a desirable and logical choice. If there are no engines to be considered as, for instance, in a straight-fuel-burning plant, a closed system answers the purpose

better than an open system because it requires less power to handle the circulation. A closed system will create a vacuum if the condenser surface is sufficiently large and the water temperature is not carried too high and if there is not too much steam to condense. As a general rule, if the hot water plant is a by-product to an electric plant, an open system is the better. If not a by-product plant, the closed system is, perhaps, preferable.

After the system has been decided upon, the details of the design can be determined. In deciding upon these points capacity and efficiency are the main features to be considered. Durability is also important and so is the expense of maintenance.

Boilers.—In selecting a boiler or set of boilers for a steam heating plant, the same features will determine the choice as in any steam generating plant. These principles are not confined strictly to a central heating plant and, for that reason, will not be discussed here. This is, however, a very important proposition and care and thought should be given the subject.

In selecting a boiler for a hot water plant there is one general principle that must be followed. It is that in circulating the water through the boiler never do this in opposition to gravity or the natural circulation of the boiler.

For examples of this principle, methods of connecting some of the boilers of different types are shown here.

In determining the size of the boilers, figure the B. T. U. or lbs. of steam necessary to supply (1) the connected load, (2) the line loss and (3) the station loss per hour, divide this by 33,000 or 30, respectively, and the quotient is the horse power necessary.

For example: Steam plant, 100,000 sq. ft. connected.

100,000 × 0.33 lbs. = 33,000 lbs. steam per hour.
Line loss = 2,900 lbs. steam.
Station loss = 1,300 lbs. steam.

37,200 lbs. steam.

$$\frac{37{,}200}{30} = 1{,}240 \text{ horse power for the maximum conditions.}$$

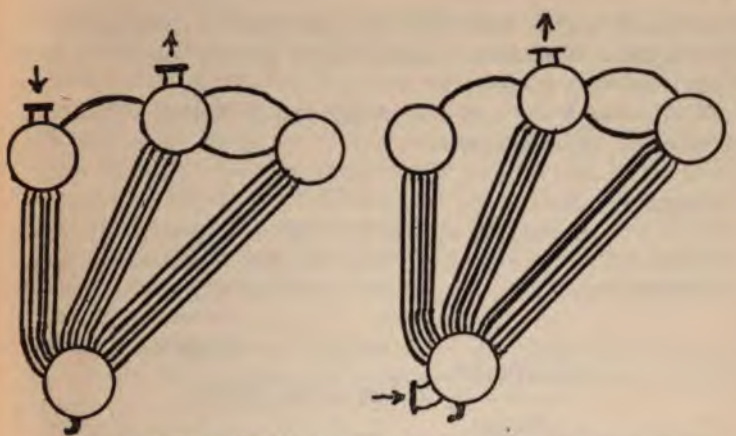

FIG. 25—TWO WAYS OF CONNECTING STERLING BOILERS

FIG. 26
ARRANGEMENT FOR CONNECTING WICKES BOILER

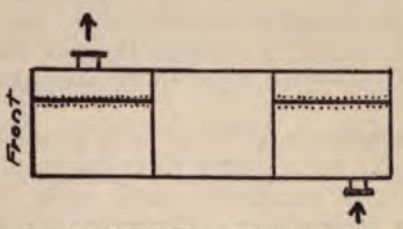

FIG. 27—ARRANGEMENT FOR CONNECTING HORIZONTAL TUBULAR BOILER

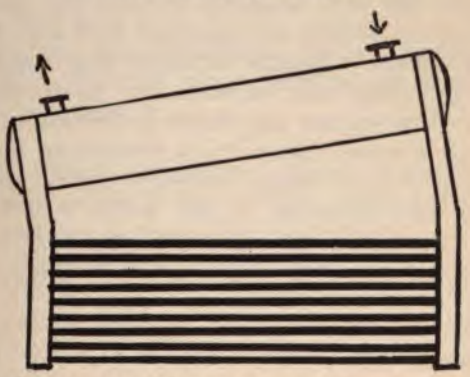

FIG. 28—ARRANGEMENT FOR CONNECTING HEINE TYPE BOILER

Any good boiler will deliver 25% over its rating for a few hours. Therefore, 1,000 horse power would be the proper amount to provide.

In figuring for a hot water circulating boiler. Example, 100,000 sq. ft. connected:

Connected load
$= 100{,}000 \times 190$ B. T. U. $= 19{,}000{,}000$ B. T. U.
Line loss $= 1{,}700{,}000$ B. T. U.
Station loss $= 750{,}000$ B. T. U.

$21{,}450{,}000$ B. T. U.

$$\frac{21{,}450{,}000}{33{,}000} = 650 \text{ horse power.}$$

Hot water circulating boilers will stand a 20% overload, so 550 would be approximately the amount to set.

Be careful to compute the line loss correctly. This is a very important point in central station heating.

Pumps.—In deciding upon a boiler feed pump little need be said here. That is a question that has already been discussed thoroughly many times.

In determining the style of circulating pump to use, the question of efficiency and capacity are important. Whatever the style adopted, be sure the machine is sufficiently large to handle the required load and has a little capacity to spare. Capacity is more important than efficiency in a pumping unit because the waste steam is used in the heating system and there is, therefore, but little waste.

The noise caused by a circulating pump is sometimes a very serious thing. A reciprocating pump causes a starting and stopping of the water which sometimes creates a knocking noise. The seating of valves is also sometimes carried along the pipe line and transmitted into the building.

A centrifugal pump appears to be the better type to handle hot water circulation. The correct capacity of the pump in this case is very essential, for these pumps operate more economically at full load than at a smaller or

greater load. We must, of course, understand that the load on a hot water plant is constantly changing, so the the best design we can hope to get is not absolutely perfect unless we should adapt a number of small units which would not be good practice. One circulating centrifugal pump should handle approximately 100,000 sq. ft. of radiation, as a general rule. This gives us an 8 or 10-in. pump.

Combining duplex and centrifugal pumps is not bad practice. In this case run the centrifugal pump to its full load and let the duplex pump float on the system working only when needed.

Pressure regulators can be used on either style pump and should be used so as to maintain an even circulating pressure.

To determine the size pump necessary, figure the maximum gallons of water needed per hour under maximum circulating conditions. To determine the head to pump against consult the pipe line layout and determine it from the pipe line curves. It is always a good idea to allow 10% greater head than the pipe line curves show, for station piping and station equipment throw considerable friction onto the pumps. If the gallons per minute and the head in feet, together with the steam and exhaust pressure, are given the manufacturers, they can determine the details as to size, speed, etc.

The impellers in centrifugal pumps to handle hot water should be made of bronze.

The means of driving the centrifugal pumps depend upon local conditions. Electric, steam turbine or steam engine drive are all practicable.

Exhaust and Live Steam Reheaters.—These reheaters of proven worth consist of three styles: (1) condenser or closed heater, (2) open heater and (3) com-mingler.

The Condenser or closed heater is of two types: (a) steam tube and (b) water tube; that is, the tubes are either filled with steam or with water. The water tube machine has been found to be the better because it is more easily cleaned and the tube area is kept open and free.

Whether these machines are set vertical or horizontal

makes little difference, provided the circulation of the water and the steam are not forced against the law of gravity. The outlet should be at the top because hot water rises. All high points in the water chamber should be vented of air and all of the steam space so arranged as to be vented of gases and condensation.

As to the size of these machines, the following will be of interest: If the tubes are of brass, as they should be, 1 sq. ft. of tube surface will transmit 200 B. T. U. per degree difference in temperature between the water and the steam.

The average temperature of the water should be considered. For example:

Water enters machine at 160° F.
Water leaves machine at 180° F.

Average temperature = 170° F.
Steam at 2 lbs. pressure = 219° F.

219 — 170 = 49 × 200 = 9,800 B. T. U. transmitted per square foot per hour under the above conditions.

For maximum conditions, figure that water leaves condenser at 210° and enters at 180° = 195° average.

This shows us that 1 sq. ft. of condenser surface will handle about 24 sq. ft. of radiating surface, either connected load, line loss or station loss under extreme or maximum conditions.

The design of the condenser should allow frequent and easy cleaning.

The Open Heater.—In the design of an open heater the number of square feet of tray surface in the heater is important. In this heater we do not ordinarily consider any purification of the water will take place but, until all impurities that will come out of the circulating water are removed, we will find a deposit in the heater. Access to all parts is, therefore, essential in the design, but for the same reason we do not need much storage space in the heater.

As to capacity, the following is a rough rule that may be used in deciding upon the tray surface: With sufficient

steam 1 sq. ft. of tray surface will transmit 1,000,000 B. T. U. per hour.

The velocity of the water leaving the heater should be sufficiently low to avoid any whirl. A whirl of the water will carry entrained air into the system. If the whirl cannot be stopped any other way, baffle plates should be installed. By all means, liberate all air and gases in the heater.

The Com-mingler.—This machine makes use of a barometric condenser head. It mixes the steam and water and at the same time causes a partial vacuum on the exhaust steam line. Extremely large quantities of steam can be handled by a machine of this kind. The capacity of the machine depends entirely upon the amount of water that will circulate through the head. The amount of exhaust steam it will consume depends upon the amount of water circulating and the temperature of the water.

A com-mingler with sufficient steam will heat water to 180° F. under average conditions and sometimes higher, but it is advisable not to figure on heating it over 180°. Use a closed heater or a circulating boiler to get the additional temperature, if any is needed.

Piping.—The design and layout of the piping in a central station heating plant is exactly like any other piping problem and need not be considered here. As to the covering to be used the author believes in highly insulated station piping, the same as in well-insulated street mains.

The different lines should be designated by their colors.

Station Meters, Gauges, etc.—On both steam and hot water plants, meters should be used to determine the output of the station. Meters are now devised that give good results in this connection. The manufacturers of these machines will furnish the correct size, if the proper data is furnished them. These meters should be recording, as well as indicating, and in a convenient place for reading.

Recording and indicating pressure gauges and thermometers should be installed wherever they will be necessary.

CHAPTER VI

OPERATION AND MAINTENANCE

Pressure Required at the Station

THIS pressure is dependent upon the pipe line sizes, the insulation and the grade of the pipe line in steam heating plants. In hot water plants it is dependent upon the pipe line sizes, the insulation, and the elevation of the heating station relative to the buildings being served.

After a plant is in operation it is an easy matter to determine the drop in pressure from one point to another and under actual operating conditions. Having determined the point on the line where the greatest drop in pressure occurs, we can determine the pressure necessary to carry at the station in order to have the required pressure at the weakest point. So much is very easy, but to determine whether or not excess pressure is being carried in order to create the necessary pressure at the weak point is quite another problem and is not so easy to determine.

Causes That Demand Excess Pressure in Steam Heating Mains

Insufficient pipe sizes is one of the most common causes of bad pressure conditions. Often a given line has developed more business than it can handle economically and

excessive pressure is required to make this line carry sufficient steam to suppy its connected load.

Improper line drainage also causes a bad pressure condition. For example, a line not properly graded, with a pocket in it, will cause no end of trouble. The pocket will fill with condensation and, even though a water hammer does not develop, the free area of the pipe is reduced, the friction increased and, consequently, the pressure at the station must be increased to compensate for this additional friction loss. The condition is often found in service lines and should be guarded against and, if possible, located and remedied by means of regrading the line or by installing additional bleeder connections.

Causes That Demand Excess Pressure in Hot Water Heating

In central station hot water heating we are not troubled so much with pockets as in steam, but the writer believes them as serious in one case as in the other. Air pockets do the damage in hot water heating and every high point should be vented and kept free from air. In this case the pipe, or a part of it, fills with air and the flow of water is restricted, requiring a greater pressure in order to give proper circulation.

Insufficient pipe sizes are also a cause of excess pressures being necessary. This defect is often caused by the territory outgrowing the pipe line.

To determine whether excess pressures are being carried, refer to your pipe capacity tables and find out if the conditions you are experiencing in your pipe line conform to the table. If not, look for the trouble.

If your operating and test observations show that your pipe line is not demanding an excessive pressure, you can then carry the lowest possible pressure that will give you 1 lb. (if steam) and 1 lb. difference in pressure (if water) at the weakest point on the line.

In hot water heating, as already stated, the difference in pressure is what you need, the circulating pressure or,

as it is often called, the differential pressure. For example, the pressure on the flow line is 40 lbs. and on the return line 30 lbs., thereby making the differential pressure 10 lbs. There must be at least 1 lb. differential pressure at the entrance of the building and each and every radiator must be full of water in order to heat a building properly. Therefore, the return pressure at the building should be sufficient to raise the water to the top of the building and the flow pressure should be at least 1 lb. more.

Locate the weakest point in this connection and be guided accordingly. As a rule, the weakest point will be at the end of some long lateral.

Pumpage in Hot Water Heating

One of the most important points in hot water heating is the amount of water pumped per square foot of radiation, per unit of time. Excessive pumpage means a waste of power and is a sure sign of poor operating conditions. To remedy this trouble it is necessary to regulate the amount of water passing through each building. To explain more fully this point we will study the following drawing.

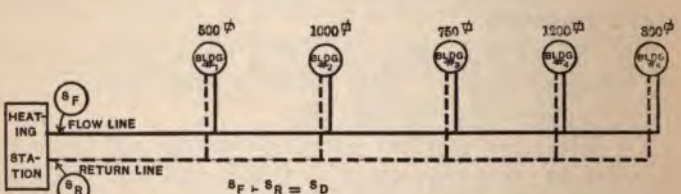

FIG. 29—DIAGRAM OF WATER FLOW THROUGH HEATING SYSTEM

We will assume that we are carrying a flow pressure at the station (SF) of 45 lbs. and a return pressure (SR) of 30 lbs. giving us a differential pressure (SD) of 15 lbs. at the station. Under these conditions we find by test that our pressure conditions would be as follows:

Position	Flow Pressure, pounds per square inch	Return Pressure, pounds per square inch	Differential Pressure, pounds per square inch
Station	45	30	15
Building No. 1	44	31	13
Building No. 2	42.5	32.5	10
Building No. 3	41	34	7
Building No. 4	39.5	35.5	4
Building No. 5	38	37	1

Now the problem to be solved is, whether or not we have excess pumpage. We know that under the conditions we have as low a differential (SD) as we possibly can have and still have one pound difference at Building No. 5. If we are pumping too much water it is going through the four jobs nearest the station.

In order to determine this it is necessary to measure the amount of water flowing through each job. This can be easily done by means of a hot water disc meter. The result will be sufficiently accurate to answer our purpose.

Pumpage Necessary

The amount of water necessary to pump per square foot of radiation per hour seems to be an unsettled question. One thing is certain; the water carries the heat and 1 lb. of water will deliver as many heat units as it loses in degrees Fahrenheit going through the radiation.

If the water loses 20° F, it will emit 20 B.T.U. per pound. If the radiation is figured so as to give off 180 B.T.U. per square foot per hour at zero, outside temperature, it would require 9 lbs. of water per square foot per hour. If we regulate the flow of water through each square foot of radiation so as to omit 30 B.T.U. per pound, it would require 6 lbs. of water per square foot of radiation per hour, at zero outside.

When the temperature outside is higher, the temperature of the water will be lower and consequently the water will not lose as much heat per pound. The amount of water pumped can be reduced some, but not to any con-

siderable extent, unless temperature regulation of some kind is used in the buildings.

Regulating the Flow of Water

We will take it for granted that we need 6 lbs. of water per square foot of radiation per hour at Building No. 1. This building has 500 sq. ft. of radiation and consequently would need 3,000 lbs. of water per hour. The differential pressure at Building No. 1 is 13 lbs. The opening necessary to supply this amount of water at this differential pressure is a 5-16-in. hole.

Building No. 2, with 1,000 sq. ft. and 10 lbs. differential pressure, would require a 13-32-in. hole.

Building No. 3, with 750 sq. ft. and 7 lbs. differential pressure, would require a 13-32-in. hole.

Building No. 4, with 1,200 sq. ft. and 4 lbs. differential pressure, would require a 5-16-in. hole.

Building No. 5, with 300 sq. ft. and 1 lb. differential pressure, would require a 13-32-in. hole.

These chokes or retarders should be placed in the return line just before it leaves the building, or on the return of each belt. The placing of these requires judgment and experience.

The total area of the chokes is found to be:

Building No. 1	5/16 in.
Building No. 2	13/32 in.
Building No. 3	13/32 in.
Building No. 4	5/16 in.
Building No. 5	13/32 in.
	1-27/32 in.

The service lines run to these buildings should be not less than 1¼-in. in diameter, even though that size is too large, for at some future time the amount of radiation might be increased and the large service line will be sufficiently large to take care of the additional load.

With this method of regulation, perfect control cannot be accomplished, but a great benefit can be derived by using it.

A number of flow controlling valves have been devised and are more or less valuable to the operating man. The cost of these valves is the only thing that stops their universal adoption. It costs comparatively little to regulate with the chokes or retarders and, for that reason, this method is much more popular. The author has used a cast-iron choke, with a hole drilled through it, and has found it to be very well adapted to this use. It is noiseless and easily made.

The automatic flow controlling valve has the advantage by being self-adjusting, while the choke system is fixed for one condition. For example, assume that an 800 sq. ft. job is connected to the system shown before, between Buildings No. 1 and No. 2. The connecting of this job will affect the pressure necessary to carry at the station and will affect the size of the choke in Building No. 1. It would have to be just a little smaller, because, owing to the necessity of pumping more water, a larger differential pressure is necessary and, consequently, more water will pass through Building No. 1 than is necessary, unless the choke is made smaller. If the additional building is connected and the pumpage is not increased, the balance of the system will be affected by not getting sufficient water.

In a case like the above, the flow controlling valve would adjust this condition automatically, because it allows only a certain amount of water to circulate through each building, no matter how much too great the differential pressure may be. On the other hand, disc or choke control has a slight advantage over the automatic valve control in one way. In choke control the pumpage can be momentarily increased on the whole system whenever it is advantageous to do so, which is sometimes the case, especially in rapidly falling temperature. By increasing the pumpage we increase the number of B.T.U. given off by each square foot of radiation, because the number of B.T.U. emitted is proportional to the difference between the room temperature and the average temperature of the radiator.

The faster the water circulates through the radiator the less heat each pound of water will emit and the less

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each pound of water emits, the hotter is the water leaving the radiator and, consequently, the higher the average temperature of the radiator, which, of course, means that each square foot of radiation will emit more heat per unit of time. This is an advantage when a severe and rapid drop in temperature is experienced. This is especially true in systems controlled by thermostats, where, by increasing the heat emission, all thermostats, almost to the shutting off place, will shut off and decrease the load on the plant temporarily and materially help in raising the temperature of the circulating water.

Temperature Required in Hot Water Plants.

As noted before, the lower the outside temperature the higher the temperature of the water should be.

To adopt a schedule for this temperature the following will be of interest:

Assume a room as below, which will act as a typical example and will show the temperature required in the circulating water.

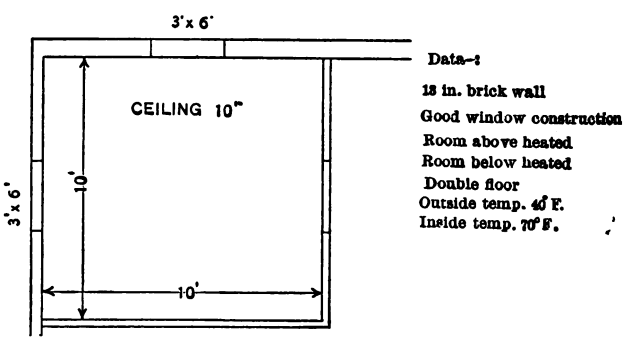


FIG. 30

Data:
Good frame wall, B. P.
Good windows.
Room over, heated.
Room under, heated.
Room adjoining, heated.

Radiation required for central station hot water is 60 sq. ft. (based on 180° F. at zero outside).

B. T. U. required for this room at different outside temperatures with inside at 70° is as follows:

Outside Temperature Degrees F.	B.T.U. Required				
	For Cubic Contents	For Glass	For Exposed Wall	Total with 10% for Exposure	Per sq. ft. of Radiation per hour "X"
60	200	430	1000	1793	30
50	400	780	1800	3278	55
40	600	1230	2300	4543	75
30	800	1655	2800	5780	97
20	1000	2150	3300	7095	118
10	1200	2420	3600	7942	133
0	1400	2700	3950	8855	148
—10	1600	3096	4264	9856	165
—20	1800	3550	4600	10945	183

From the foregoing table we can determine the temperature necessary. We must allow for line loss and for the cooling of radiator, for the B. T. U. emitted from a radiator depends upon the average temperature of the radiator.

The formula to use is:

$$\text{F. T.} = \frac{X}{1.65} + 70 + L$$

where

F. T. is the temperature of the flow line.

"X" is B. T. U. emitted per square feet per hour from the foregoing table.

L is the drop in temperature from the plant to the average temperature of the radiator, which varies from 12° to 23°, depending upon the outside temperature.

The following is a schedule for 180°, 190° and 200° basis:

Outside Temperature Degrees F.	Temperature of Flow Line, Degrees F.		
	180° Basis	190° Basis	200° Basis
60	100	110	120
50	121	131	141
40	135	145	155
30	147	157	167
20	158	168	178
10	169	179	189
0	180	190	200
−10	191	201	211
−20	202	212	222

NOTE: Add ½ of one degree for each mile of wind over 5 miles per hour.

Maintenance

Maintenance of heating property might be called the care necessary to keep the property in first-class condition. The maintenance of the heating station is very similar to any steam-generating or coal-burning plant. It seems unnecessary to mention the essential points in this connection, but too much can never be said on this point. It is obvious that in any plant the old saying, "a stitch in time saves nine," is very true. Procrastination in this respect is decidedly costly and detrimental to good results.

At the first sign of weakness the weakest part should be replaced or repaired at once. It is often a question whether to repair a weakened part or to replace it with a new one. That can only be decided by experience, but "when in doubt replace it" is a good proverb to remember and to be guided by, especially if the part in question is of any importance in giving uninterrupted service. Every little detail should be carefully watched. If the needed repairs and replacements are allowed to go unheeded the inevitable result will be a breakdown with the cost of repair increased many times.

If a plant is allowed to get dirty it soon develops careless habits among the employees and this, of course, is bad. Keep the floor of the plant swept up and use a little paint now and then. It all helps wonderfully. Cleanliness and neatness will

give greater returns per dollar spent than any other little thing that can be done. The manager, superintendent and chief engineer should be cranky on this subject. The details of maintenance of boilers, furnaces, pumps and other machinery are well known and understood and will not be noted here.

The care of the pipe line in a heating system is very important and also comparatively easy. As a general rule it is not a good policy to be looking for trouble, but in pipe-line maintenance it is the opposite—we should be looking for trouble so that the instant anything develops it can be remedied.

Leaks are the worst of all troubles, due to the deteriorating effect they have on the line. A leak of either steam or water causes the pipe to corrode, the covering to deteriorate and the efficiency to decrease. The loss of heat in the leak itself is sufficient to warrant immediate repair, but this loss coupled with the permanent depreciation of the pipe line makes it all the more important that this deteriorating cause be stopped.

It is not difficult to locate leaks in a pipe-line system. In any system the leak will either show up on the surface of the ground by melting the snow over the line or by causing a wet spot to appear. If the street is paved or for any other reason the dampness cannot get to the surface the condensed steam or hot water will follow the conduit, covering or underdrain to the nearest manhole and can be detected there.

It is at these places that we should be looking for trouble. Oftentimes a leak will make sufficient noise to be heard quite a distance and listening for this noise will often help. It is probably unnecessary to explain how to discover leaks. It requires only a little common sense.

If the piping is made up in place by an experienced pipeline foreman there is little chance for leaks. Before the pipe line is covered it should be tested or, at least, a test applied before the line is completely covered, so that a leak can be detected easily if there is one. After the line is once tight there is little chance of a leak developing except at the moving parts and these moving parts should be so arranged as to allow frequent and easy inspection. It will be noted that while leaks are very bad, yet the possibility of leaks in the

pipe is very remote, but in the moving parts this is different. In these places leaks are apt to develop, and while the effect on the physical condition of the line is not as bad, for the reason that moving parts are usually in a manhole, yet the loss of heat from a leak of this kind makes it imperative that the leak be stopped.

Underdrainage is also important to the life of a pipe-line system if, of course, the line is not laid in a loose soil such as sand or gravel. If it is laid in that kind of soil extreme care should be taken, to be sure that there is no chance for any water to stand around the pipe line, and, if there is the least doubt about it, put in the underdrain. It is necessary to keep the underdrain working and inspection holes should be put in the drains at manholes so that it can be seen that it is operating. Tests should also be made from one manhole to the next to prove that the drain is open. This can be done by pouring water into the drain and seeing it pass the next inspection hole.

If the pipe line is kept dry the efficiency is kept high, but if the line is covered with water the efficiency is reduced many fold and, in addition, the covering is materially effected by being wet or by alternating dry and wet conditions. It is obvious, therefore, that it is essential that the line be perfectly drained.

Traps should be cleaned and inspected regularly. Of course, traps are used only on steam systems. It is necessary to have a by-pass around the traps so that the traps can be taken out and cleaned and not interfere with the operation of the line. If a trap should stop operating it will not cause any serious result, as a rule, but it can cause a water hammer, consequently it is bad policy to allow a trap to stop. They should be inspected at least once a week unless experience has taught that is too often, which the writer thinks will not be so. Traps are usually set in a manhole or in a place that can be entered often and easily.

The traps should be connected with a sewer or some convenient drain for handling the condensation. Cooling coils of some kind should be arranged so as not to cause vapor to rise from the sewer connections to the street.

Meters demand close inspection and, as these instruments are used to measure line condensation, we must consider their care under pipe-line maintenance. It is especially essential to watch the meters to see that they are clean and operating perfectly. Meters should be tested every year and cleaned at least once every year. It is often necessary to clean them oftener, especially on a new installation and, for that reason, a by-pass should be installed around the meters as well as the traps. Between the meter and the trap a telltale pipe should be connected so as to allow inspection to ascertain whether or not the trap is blowing steam.

Always place the meters and traps in as dry a place as possible and place them in such a position that they can be taken out and cleaned without much work. Keep them well painted and free from rust. During the summer months both the meters and the traps should be taken out of the manholes and cleaned, painted and tested. Then when the heating season starts they are in fine shape.

Expansion joints should be watched, but they are such a small care that little need be said about them. Keep the brasses clean and free from foreign matter and keep the packing boxes full and not pulled up too tight. The same can be said of valve stems. Keep them packed well and pulled up just enough to stop any leaks around the stem. It is often advisable to place a shield in the form of a half-circle over the brass sleeve of the expansion joint to protect it from scratches caused by stepping on it in getting in and out of the manhole. These shields do not cost much and are very serviceable.

All cast-iron fittings and all pipes that are not covered and the inside of all manhole covers should be kept well painted with a good quality of iron paint.

Avoid letting any surface water drip through the manhole covers. This can be easily done by casting a trough on the inside of the manhole cover frame to catch this water and pipe it away to the underdrain or sump in the bottom of the manhole. If the manhole covers are already in place without the trough it can be easily made of heavy galvanized iron and attached to the frame.

As stated before, we should not wait to have troubles show themselves on the surface before attending to them. Dig into the proposition and find out if there is anything wrong.

Pipe-line maintenance is not expensive. It is a very small percentage of the original cost. On a plant with five and one-half (5½) miles of mains and laterals, one man at $75.00 per month and a helper at $60.00 per month can completely overhaul the entire line in thirty days in the summer and one day a week will suffice for inspection and repairs during the heating season. The cost of material for the repairs and maintenance will average about $220.00 per year for five miles or about $40.00 per mile per year. The labor per year amounts to approximately $315.00 or about $57.00 per mile per year. As the average pipe line costs about $25,000.00 per mile, we can see the maintenance is less than one-half of one per cent. per annum of the first cost, which is a decidedly low maintenance cost and a property can be maintained properly for that amount. There is, then, no excuse to offer for not using all diligence in maintaining the pipe line properly. A property well maintained will depreciate in value to a far less extent than if not kept up.

Depreciation and maintenance are closely allied.

CHAPTER VII

Management

THE management of a public utility requires system as well as a lot of good common sense. The extent of the system that can be profitably utilized depends a lot upon the size of the utility. In other words, an elaborate system would be decidedly detrimental in a small organization, for there would not be sufficient employees to handle it and keep it going, to say nothing of keeping the plant itself going. Any system is liable to get top heavy if too elaborate and, on the other hand, a management without a system or plan of operation is an absolute failure.

To find the system best adapted to each case requires thought and study and, as stated, a good portion of common sense.

A good definition for the word system as used by public utility managers is "A plan of management," a general rule or set of rules guides the management of a property. The plan, or, at least, each one's part in it, should be indelibly stamped on every employe's mind. It should be easily understood and made plain to every man or woman in the organization.

It has been said that in unity there is strength. We cannot have unity without organization and we cannot have an organization without a system. System is as necessary in a public utility organization as laws are in a state. Without laws in a country we have anarchy and without system in a

utility management we have failure. We have reached a point in public utilities where every manager realizes this point so that little can be said to strengthen the argument.

In adopting a system there are a few general points to be observed and kept in mind. The object of the system is to develop the utility to the best possible condition, both with respect to its physical condition and its financial condition.

In order to develop and maintain a good physical condition it requires experience and careful detail management.

To develop a good financial condition requires sometimes more than human effort can produce. But in many cases system will bring the desired result, provided, of course, that it is a possibility.

A central heating plant has three general features, like any other business:

First—We must manufacture our product, heat, as cheaply as possible.

Second—We must transport or distribute heat economically.

Third—We must make our product attractive.

Our field is limited to the city or district in which we are doing business and we are limited to this field. There is a definite and fixed number of consumers and a definite and fixed amount of business to be obtained; consequently, one important fact presents itself; never lose a consumer if you can keep him by reasonable and consistent means.

Owing to the peculiar attribute called human nature there are some people who cannot be satisfied and whom you cannot expect to keep as consumers, even if you are able to serve them originally. These people should be treated nicely, but forgiven and forgotten as soon as possible.

As a rule, quality of service is remembered long after the price is forgotten, so every means to give the best service should be employed. The price should be kept as low as can be done consistently without interfering with the good service necessary. The competition of the isolated heating plant is always sufficiently strong to prevent any danger from exorbitant charges. If a man can heat his building for $50.00 per year, it is difficult to get him to pay you $100.00, but do not overlook the fact that you heat him

perfectly for 24 hours while he has been heating himself only part of the 24 hours. Remember, also, that after you have heated him perfectly for one season you have a life-long consumer.

Now the point arises, how to give the consumer perfect service. This requires station capacity, pipe line capacity and sufficient radiation capacity in the consumer's property to give him sufficient heat. It often requires that attention be given to the condition of the consumer's buildings to see that windows are kept in proper repair, that bad and defective construction be remedied, that unnecessary ventilating ducts, such as chimneys, are closed tight and that wasteful methods of using heat be stopped. This should be done whether the heat is sold on a flat rate or meter basis. Of course, if the defect lies in the station or pipe line, it is obligatory on the part of the utility to remedy the trouble at once. If the defect is on the consumer's premises it is for the consumer to fix, but the utility management should guide the consumer in these necessary repairs and insist that the repairs be made without delay.

If the consumer's premises are in proper shape and proper repair over half the battle is won, but it often takes tact and untiring efforts to bring about this result. There are no set of rules that can be set down to guide the management in this task. One thing can be noted, however, that if the management is doing all it can to remedy these little troubles, the consumers, if properly handled, will ordinarily meet it half way.

Do not suggest a repair unless you know it will be helpful to the cause. If you do you will lose the confidence of the consumers and nothing is as essential as the consumer's confidence in the management.

General rules and principles for pipe line troubles and repairs have been given under "Pipe Line Operation."

As to the system to be followed in the heating station so as to manufacture heat economically, a great deal can be said, but the operation of a heating station is so similar to the operation of any fuel-burning plant and these principles have been so generally expounded that it is considered needless to go into them in detail here.

A few of the more important points will be mentioned because they are so important and because they should be kept in mind.

The care of the boilers is very important. The management should know that the boilers are kept clean and should have a record kept of the time each boiler is cleaned. Do not depend on the record to know that they are clean, but see to it that they are cleaned both inside the tubes and outside. A personal examination of the boilers by the manager or his superintendent is often advantageous, especially to prove beyond a doubt that the system of watching this one point is working.

No boiler can be too clean. The combustion of the fuel is also very important and a system can be adopted that will materially advance economical operation. Flue gas analysis is essential in this connection. The check this has on the firemen is far reaching. It shows what economy is obtained and allows the weak points to be discovered and remedied. The point to be watched by the manager is that these tests are made regularly and a record kept so that they may be referred to at any time. It is often advantageous to work out a system of credits and debits which will increase or decrease the fireman's wages in proportion to the economy he develops. In a heating plant so great a percentage of the operating expense is fuel that a small leak in this department often means financial failure.

The kind of coal to burn, if a coal-burning plant, is decidedly important and the author's experience has been that an operating test is the only sure method of ascertaining which size and which quality of coal to buy. By operating test is meant a test that takes into consideration every possible phase of the operating condition, such as cost of fuel per 1000 lbs. of steam, or 1,000,000 B. T. U. generated by the boilers; the effect on the grates or stokers; the handling of the ash; the labor handling the fires with the coal, etc. This test is invaluable to the manager and when the best grade and size of coal are known, a great deal of trouble and dissatisfaction is stopped.

This is one of the most difficult things a manager has to

decide and, in order to decide it, a system must be used and used effectively.

In order to determine the cost to generate 1000 lbs. of steam or 1,000,000 B. T. U., it is necessary, of course, to measure the output of the plant. This can be done in a steam plant by measuring the boiler feed water and taking the temperature of the water before it enters the heater, or economizer, or by meter direct. In a hot-water plant the amount of water flowing should be measured and the temperature of the water, both flow and return, should be recorded. Recording meters and thermometers are made for this purpose and are very reliable. It is also necessary to keep a record of the weight of coal burned and, oftentimes, to keep a record of the ash removed, the number of times the boiler needed cleaning, the amount of time consumed in firing, cleaning fires and removing ashes. In this way the general result can be obtained in each of its separate parts and for each different grade of fuel.

The same system can be adopted in handling the machinery. A record should be kept of the time devoted to the repairs and maintenance of each piece of machinery, the amount of oil used and the cost of new parts. It does not take much of the fireman's time nor much of the engineer's time to keep these records and they are invaluable to the manager.

The manager should keep posted as to the weather. What the weather is going to be and what it has been. It is important to know if a cold wave is expected so that every part of the plant can be ready for it. The local forecast furnishes this information to a great extent. The advantage to be gained by a record of the weather (temperature, wind and humidity) that has passed, is of special benefit in handling complaints about extremely high monthly bills. In this connection it might be mentioned that a real live manager soon learns the habits of each consumer as to his economy or wastefulness in using heat. This is an important point and one that should be studied by every manager.

Recording gauges and thermometers should be used on every vital part of the system so that the manager can

have a check on the operation of the plant at all times, and in that way can decide whether a complaint as to insufficient heat is justified or not.

The maintenance of the pipe line is not a large item of expense at any time, but it is decidedlv important. If a leak develops it can cause expensive trouble and should be fixed at the earliest possible moment. It not only wastes heat, but it has an exceptional deteriorating effect on the pipe and insulation. Expansion devices should be inspected regularly. Line traps and meters should also be watched and kept clean.

The consumer's equipment should be examined regularly. The meters and traps should be inspected and kept in good repair. Do not wait for a complaint before doing this. Do it of your own accord as it will win you a lot of friends and will materially reduce the number of complaints.

One of the greatest sources of complaint any utility can experience is that caused by the procrastination of its employes. If you have a complaint, remedy it at once or, at least, attempt to remedy it. Do not try to mislead your consumers. Be prompt and impress it upon your employes that proscrastination will not be tolerated.

New Business Department

This branch of central heating is especially important in a new plant. A heating plant designed to handle 200,000 sq. ft. of radiation cannot be made to pay with a small load connected; for that reason it is essential to load the plant as soon as possible. A new business campaign can be inaugurated that will pay big. Good, catchy advertisements will help and so will a personal canvass by the solicitors and the manager. Each particular case should be carefully handled and the manager can afford to give this department a large share of his time, especially after the plant is shut down in the spring.

Central heating is very attractive and after a consumer once has it he very seldom discontinues it, if the service is properly maintained. One satisfied consumer will bring you more, so do not be afraid to refer to your consumers as refer-

ences. After a plant has been in operation a season or two, advertising will not bring large results, but the first year or so it helps wonderfully for it educates the public to see what a comfort and pleasure you have for them.

This branch of the business has been given a great deal of thought and study the last few years, and the results obtained are indeed gratifying.

The development of new business in central heating is more or less limited as compared with electric light and power. In a territory such as a central heating plant would serve, there is a greater volume of heating business than there is of electric business. This is especially true of the business district in a city and also true of the residence section. There are, of course, sections in every city where this is not the case, where large power loads are developed. From the above fact the electric end of a by-product plant should extend into territory beyond the heating zone or, in other words, in order to keep the two loads well balanced it is often necessary to put a great deal of effort in the new business department of the electric plant to keep pace with the heating requirements.

Do not consider, however, that the heating business does not need attention for it does, although I think there is less trouble, per dollar invested and per dollar earned in a heating plant than any utility I know of, if the property has been built right at the start.

Another point which makes the new heating business department of a by-product plant necessary is the fact that all electric consumers are using more current per consumer than they used to. The introduction of fans, irons, washing machines and the like are developing the electric loads rapidly, thus allowing more waste steam to be used in the heating plant and, as it is desirable to make the heating plant earn as much per foot of pipe line as possible, it is better to develop the territory already served than to construct new lines. While our field is more or less limited to a given territory, a wonderful amount of business can be developed if the proper effort is made. The domestic hot water can be heated by the central station service and store

windows properly heated and ventilated will be free from frost.

There are, of course, no bargains to be offered the consumer from time to time to induce new consumers to connect to the plant, but the comfort to be derived from the service is an inducement sufficient to bring a large volume of business, if the proper effort is made to acquaint the people with the facts. What can we imagine more delightful than a home heated evenly and sufficiently all winter from the time heat is needed in the fall until it is not needed in the spring, with a supply of heat that heats every room in the home at any time of day or night, with a supply of hot water for bath purposes always ready, with a supply of heat sufficient to heat any fresh air needed for ventilation and all this without one iota of trouble or annoyance to the consumer? Even though it does cost a little more than the isolated plant per year, which, by the way, is not always the case, the difference in cost is nothing when the additional comfort is taken into account.

In this chapter the author has tried to bring out a few of the important points in the management of central heating plants, but, after all is said and done, a lot of good business judgment will do more to attain success than anything else. A central heating plant is probably as easy to run as any utility. If any operator or manager gets a new thought or a new idea from this chapter its mission will have been accomplished.

CHAPTER VIII

Franchises

THE author's experience in drafting franchises and in acting for cities in a consulting capacity relative to heating franchises has prompted him to insert one chapter on Heating Franchises with the hope of clearing up some of the often misunderstood points.

It is customary to assume that anyone trying to obtain a heating franchise is endeavoring to get something for nothing and that the cities are giving away millions of dollars when they grant a franchise of any kind.

This impression is gradually becoming a thing of the past, due to the general public becoming better acquainted with the real facts and also due to the old-fashioned unscrupulous franchise grabbers having been replaced by more honorable men who want a reasonable return on the money they invest in a heating plant but do not ask or want an unreasonable franchise.

A heating plant in any city is a great public improvement and an undertaking that should be encouraged, at least, to the extent of a reasonable franchise—one under which the heating plant can prosper and give to the community good service at equitable rates.

In order to determine what would be an equitable and reasonable franchise is not an easy thing and demands much study and work, especially from those who are not familiar with all the underlying conditions. The public

utility commissions have not taken up the question of heating rates or franchises to any definite extent, but the rulings they have made relative to other public utilities can be utilized in handling heating franchises and rates.

One fact should become strongly impressed on the mind of every city official who is considering a heating franchise. It is this: the city should demand and the grantee give good service and the company should demand and the city should allow a reasonable return on the money invested.

It is, therefore, equally as important to both the city and the company that the franchise be so drawn as to allow both good service and reasonable returns on the money. If good service is not maintained the company cannot keep its consumers and, if the company is not financially successful, it cannot stay in business and a financial failure not only affects the company, but the whole city as well, in a general way, and is a situation to be deplored.

In the term "good service" a great deal is contained. The quality of the service should be good. The quantity of the service, if that word can be used, should be equally as good. By the word quantity, the author means the number of people who can take advantage of the service. In other words, the company should serve as large a territory as possible without causing a loss to the company. This point is, relatively speaking, of minor importance, for every heating company will want to expand as far as they can consistently, yet often a company may not expand as fast as the city requires and, for a safeguard, the city should insert a clause in the franchise covering this point; as, for example, the company should extend its mains —— feet if the consumers on the extension would guarantee to use or pay for at least $—— worth of service each season. The number of feet and the number of dollars can be determined only after all conditions are known.

The quality of the service is equally as important to the company as it is to the city and, for that reason, the company should not object to the city's demanding a reasonable assurance of getting good service by asking that a

clause be inserted in the franchise stating definitely the season during which heat is to be furnished continuously, as well as the pressure and temperature to be maintained in the heating mains and services. This clause is no hardship on the company if, of course, the company is not held liable for damages caused from lack of service when due to accidents, strikes, etc., or when caused by the interruptions due to the necessary repairs and maintenance of the heating system.

The company should not be held liable in any way, under a franchise, for the operation of the equipment in the consumers' buildings, for this equipment is the property of the consumer and the company has no control over other people's property. It is essential to good service to demand that the consumers' equipment be subject to the approval of the company, both before service can be demanded and during the time the consumer is being served. This arrangement will obviate any misunderstanding and make the company's position definite.

The subject of rates is very important and is taken up in another chapter.

It is generally conceded that no company would ask for a franchise to operate a heating plant unless its officers knew what they could do with the property after they had it, and, for that reason, the city officials often consider it none of their business what a franchise demands, so long as the city's position is safeguarded and the rates are kept down. This position is probably taken because of the impression that all franchise getters are grafters and are only after the millions of dollars that the city is giving away.

This position is absolutely wrong and any city official who assumes it is absolutely wrong and a poor official to represent the people. In order to pass on a franchise intelligently, it is necessary for him to study the history of heating plants and acquaint himself with the facts. If obtainable in no other way, the board of works, or the city councils, or whatever board passes upon a franchise could afford to spend a little money to get this informa-

tion, either by getting data from other plants and from other cities or by retaining a central heating engineer to guide them in the matter.

The term of a franchise, or the length of time it is granted for, is an all important point. Some states have limited the number of years that a franchise can be in force, while, in other states, an indeterminate franchise can be granted. Exclusive franchises are never granted any more, except under the control of utility commissions and, while the different commissions have no power to grant exclusive franchises, yet they will not allow a competing utility to enter the field unless public necessity and convenience demands it. Thus a utility under commission control need not be afraid of competition as long as it is giving good service at reasonable rates. The question of indeterminate franchises without competition is one that is receiving a great deal of thought at the present time. Indeterminate and exclusive franchises, properly controlled, are really the logical, and most equitable, franchises that can be granted for the consumer, the public and the heating company. This may be a strong statement to make, but it is, nevertheless, the truth. The term "properly controlled" is broad in its meaning and its effect. The two points in the operation of any public utility that affect the consumer and the city in general are the rates charged and the service rendered. These two points are the only ones that need regulation and control and, if these are properly regulated, there is no need of competition in the utility field. The scientific basis for rates depends, to a certain extent, upon the cost of the property and, consequently, the financing of the company is important because, if watered securities stand against the property, it is not equitable to allow reasonable returns on the watered securities, for it represents no real investment of money.

Utility commissions have assumed this control over public utilities and it can safely be said that it has been a boon to the smaller plants to have had these commissions created.

There are many states without any commissions to control utilities and in these states the municipalities are

obliged to safeguard their own interests in granting a franchise for a heating plant.

The following outline will be of use in drafting a franchise. It covers, in a general way, all necessary points. The legal phases of franchises have not been considered. It should always be remembered that a franchise grant is given only for a stated or implied consideration and this consideration may be stated definitely or may be merely implied.

General Outline of a Franchise

I. Title.

II. Establishing clause.
Defining rights and purpose.

III. Conditions and restrictions.
Rates and special clauses.

IV. Signature of proper officers.

V. Acceptance.

VI. Bond (if any).

Under No. II the following points should be covered:

1. Authority conferred { to whom. / by whom.
2. Length of time for which granted.
3. For what purpose.
4. To serve whom.

Under No. III cover the following:

1. General ordinances already passed.
2. City approval of location of work.
3. Excavations and obstructions. Protection of city from any damages.
4. Legal protection for city.
5. Rates to be charged.
6. Franchise tax or compensation to the city.

7. Repairing streets, city's approval.

8. Service to be rendered.
   Quality.
   Duration.
   Territory to be served.

9. Map of underground work to be filed by company and kept up by company.

10. On what account valid or void.

One of the many considerations often asked by a city is a percentage of the gross or net earnings, or free heat for some of the public buildings. This may properly be called a franchise tax and it is an open question whether or not it is equitably imposed. If the amount of the tax comes directly from the stockholders of the company and after the holders of stock have received a reasonable return on their investment, the tax might be equitable, but, in all cases, the company's consumers pay this tax indirectly, because the money for this tax is received from the company's only source of revenue, the consumer.

It does not seem equitable that the city's income should be derived from consumers who are benefiting the city by using the central station heating service, we say benefiting the city, because the use of central station heating plants does away with the dust and dirt ordinarily caused by many smoking chimneys, through using the proper equipment to do away with smoke, which they can afford to do on account of the size of its units.

Another point that is of note is the fact that a central station heating plant does not mar the beauty of a city in any way. It is contrasted with the telephone and electric light companies, with their poles and overhead systems, and it is contrasted with the street railroads, with their overhead construction, to say nothing of their use of the streets occupied by their tracks. A central station heating plant has none of these objectionable features, for its distributing system is underground and out of sight and, in addition, it is the only practical solution of the smoke nuisance.

It is also significant to note that the public in general does not use the service of a central station heating plant as it does other utilities. Consequently, the tax, if one is imposed, is paid by only that portion of the citizens who are consumers.

If a tax is imposed it should be contingent upon the heating company having first received a reasonable return on the money invested. In other words, the city's compensation should come from the net earnings after interest, depreciation, taxes and insurance have been taken out. The usual way is to divide the surplus remaining between the city and the company.

Two franchises are given herewith with the cities' names left out. These instruments show in detail many points of interest.

FRANCHISES

Steam and Hot Water Franchise

CONTRACT between Board of Public Works of the City of ———, ———, and ———, successors and assigns, granting the right-of-way, over, along and upon the streets, alleys and public grounds of said City for the construction, maintenance and operation of a plant for the manufacture and distribution of steam or water, or both, for heating and power purposes.

THIS AGREEMENT, Made this ——— day of ———, A. D. 1909, by and between the Board of Public Works of the City of ———, ———, hereinafter called the Board, and ———, of ———, ———, successors or assigns, hereinafter called the Grantee, WITNESSETH:

ARTICLE 1. The right, privilege and franchise is granted unto and vested in the Grantee for the term of twenty-five (25) years from and after the date of this Ordinance to enter into, upon or under any streets, avenues, alleys and public places in the City of ——— and therein to construct, lay, operate and maintain a system of pipes, mains, conductors and service pipes, with all necessary branches, cut-offs, manholes and appurtenances, for furnishing and conveying hot water or steam for heating or other purposes to public or private consumers, within the said City of ———.

ARTICLE 2. The said Grantee may enter into, upon or under any of such streets, avenues, alleys and public places from time to time as may be necessary for the purpose of laying, maintaining, operating and renewing such system or any portion thereof, but in so doing shall not cause any permanent injury to any such streets, avenues, alleys or public places in the said City and in such manner as not to interfere with any water or gas pipe, public or private sewer, electric wire or cables, or other conduit for same, now or hereafter laid or constructed by the said City or any authorized person or corporation.

ARTICLE 3. The said Grantee shall replace and repair all streets, avenues, alleys, private or public places, sidewalks and pavements removed by them, and shall fill up all excavations and restore all of such streets, avenues, alleys, private and public places to as nearly the same condition as they were before the commencement of such excavations, as is practicable, subject, however, to such further regulations therein as the City Council may prescribe, and they shall properly guard and protect any and all such excavations made by them, either in putting in, taking up, replacing or repairing any of such mains, pipes or appurtenances by such suitable lights, barriers and other protection as may be necessary and proper, and they shall be liable for any and all damages occasioned by any failure whatsoever to guard and protect any and all person or persons and property from any injury, by reason of any such excavation and the costs and expense of any and all such suits against the City of ——— and final judgments obtained by reason of any injury incurred thereby, shall be paid by the said Grantee.

ARTICLE 4. Heat shall be furnished by the said Grantee from September 15th to May 15th during each heating season of the life of this franchise, whenever the outside temperature shall be sixty degrees (60°) or lower and the rate of service shall not exceed twenty cents (20c) per square foot of radiation per season for hot water radiation, based upon the radiation being set so as to maintain seventy degrees (70°) in the buildings with twenty degrees (20°) below zero outside, with circulating water entering the building at two hundred degrees (200°), or the rate for steam heat service shall not exceed thirty-five cents (35c) per square foot of radiation per season, based upon the radiation being set so as to maintain seventy degrees (70°) in the building at twenty degrees (20°) below zero outside, with one pound (1 lb.) pressure at the building, and on a meter basis at:

75c per 1000 lbs. for the first 10,000 lbs. per month.
70c per 1000 lbs. for the next 10,000 lbs. per month.
65c per 1000 lbs. for the next 10,000 lbs. per month.
60c per 1000 lbs. for the next 20,000 lbs. per month.
55c per 1000 lbs. for the next 50,000 lbs. per month.
50c per 1000 lbs. for the next 200,000 lbs. per month.
45c per 1000 lbs. for the next 300,000 lbs. and over per month.

ARTICLE 5. The said Grantee shall within sixty (60) days from and after the date of the passage and acceptance of this Ordinance begin work on the heating system under the terms and conditions of this franchise, and shall construct its heating plant and shall have a system of street mains ready and in operation in at least a portion of the City covered by this franchise within eight (8) months from and after the date of the passage and acceptance of this Ordinance, and upon the Grantee's failure so to do, it shall forfeit all rights and privileges under this Ordinance and the same shall be null and void. Thereafter, it shall be required to extend its system of mains, wherever practicable, to furnish service in each contiguous block or square whenever petitioned to do so by one or more freeholders within said contiguous block or square, who in the aggregate will contract to take at least two thousand (2000) square feet of radiating surface and to pay for the same for the

period of one (1) year from the date such service shall begin, at the prevailing rates at the time of entering into the contract.

ARTICLE 6. The said Grantee shall have the right to tap or connect with any sewer in any street, avenue, alley, private or public place to be occupied by any of the pipes, mains, conductors, services or appurtenances of the said Grantee's for the purpose of draining any of such system of pipes, mains, conductors or appurtenances laid by the said Grantee; provided, however, that the detail and purpose of such tapping or connections shall be made and filed with the Common Council of the City of ———, and after their approval a permit shall be granted and the work done under the supervision of the City Engineer.

ARTICLE 7. In the construction of the said system, the Grantee shall be compelled to lay and construct its system of street mains, service pipes and other appurtenances with due conformity to established grade lines of the streets, avenues, alleys and other private and public places, and all such system of street shall be laid at such depth as to give a covering over the top of the conduit of not less than two (2) feet, excepting in crossing gutters or meeting other unforeseen obstructions, then the Grantee shall have a leeway of one (1) foot of covering of the said conduit.

ARTICLE 8. Upon the completion of the system of street work, the said Grantee shall furnish the said City a detail drawing of the entire underground work drawn to scale, showing thereon the full and complete plan of its system of street mains, service pipes, expansion joints, valves, manholes and other appurtenances, and upon making further extensions and connections to the initial system the said Grantee shall immediately revise and add to the said drawing, showing thereon all additional mains, service pipes, manholes, valves, expansion joints and other appurtenances additionally constructed as aforesaid.

ARTICLE 9. Wherever the said Grantee shall desire to construct or lay in or under any streets, avenues, alleys or other private or public grounds, any pipes, mains or other appurtenances used in the construction of the said heating system, the said Grantee shall make application therefor in writing to such officer of the said City of ———, as may be designated by the Common Council for such purposes, and the said Grantee shall first secure a permit therefor, and when the work for which said permit is secured and issued shall have been completed, the said Grantee shall report such completion to the said officer, and whenever the said Grantee shall desire to relay or repair any pipes, mains or other appurtenances previously laid or constructed, pursuant to the right herein granted, the same shall be done under restrictions and subject to the same approval and conditions herein contained in relation to the original construction.

ARTICLE 10. Within ten (10) days after the passage of this Ordinance and the approval of the same, said Grantee shall accept the same in writing by filing a written acceptance thereof with the Clerk of the said City, and within thirty (30) days after the passage and approval thereof, the Grantee shall file with the said Clerk a good and sufficient bond, subject to the approval of the

Common Council of the said City, in the penal sum of TEN THOUSAND DOLLARS ($10,000.00) conditioned upon the full and faithful performance of all the obligations imposed upon the Grantee by this Contract, and which bond shall insure to the said City a full compliance with the method of construction and repairs required by this Ordinance and the payment of all liabilities imposed thereby for any failure to comply therewith, which bond shall be of such a character as to give original jurisdiction to the Courts of ——— County, in the State of ———, which bond shall be a continuing bond, or shall be renewed annually during the term of this franchise.

ARTICLE 11. On or before the first day of July, during each year of the life of this Ordinance, the Grantee shall render to the City of ——— an accounting of the gross earnings, operating expenses, taxes, insurance and depreciation reserve, caused by the operation of the heating system under the terms of this franchise.

After the Grantee has paid six per cent (6%) interest on the capital invested in the system installed, then the surplus earnings, after paying operating charges, depreciation, interest on the investment, etc., shall be divided equally between the City of ——— and the Grantee.

IN WITNESS WHEREOF, The parties have executed this agreement in duplicate the day and year aforesaid.

.....,
.....,
.....,

Board of Public Works of the
City of ———, ———.

.....,
Grantee.

FRANCHISES

Steam Franchise

A CONTRACT BETWEEN THE CITY OF ——, ——, BY AND THROUGH ITS BOARD OF PUBLIC WORKS AND ——, ITS SUCCESSORS AND ASSIGNS, GRANTING THE RIGHT TO ENTER UPON THE STREETS, AVENUES, ALLEYS, LANES, COMMONS AND PUBLIC PLACES OF THE CITY OF ——, ——, AND THEREIN TO CONSTRUCT, LAY, OPERATE AND MAINTAIN A SYSTEM OF HEATING CONDUITS, PIPES, MANHOLES AND ALL NECESSARY APPURTENANCES FOR THE DISTRIBUTION OF STEAM FOR HEATING AND OTHER PURPOSES TO PUBLIC AND PRIVATE CONSUMERS WITHIN SAID CITY.

THIS AGREEMENT, Made this —— day of February, A. D. 1911, by and between the City of ——, ——, by and through its Board of Public Works, party of the first part, and ——, a corporation organized under the laws of the State of ——, party of the second part, witnesseth:

That the party of the first part does hereby grant unto the party of the second part, its successors and assigns, for a period of twenty-five (25) years from and after the date hereof, permission, license and authority to enter upon the streets, avenues, alleys, lanes, commons and public places of the City of ——, ——, and therein to construct, lay, operate and maintain a system of heating conduits, pipes, manholes and all necessary appurtenances for the distribution of steam for heating and other purposes to public and private consumers within said city, which grant is and shall be upon the following conditions, to wit:

SECTION 1. When the party of the second part shall desire to construct or lay any heating conduits, pipes, manholes or appliances for the distribution of steam for heating and other purposes as aforesaid, it shall prepare and place on file in the office of the Board of Public Works, at said city, maps, plans and specifications

of such proposed construction, which maps, plans and specifications shall include all excavations and all apparatus and appliances of every kind and description, showing the general character of the proposed construction, the exact location of the conduits, pipes, manholes and all other necessary appurtenances, and shall conform in all respects to the provisions of this contract and any ordinance of the Common Council relating to public safety and health, which maps, plans and specifications shall be approved, without unnecessary delay, by the party of the first part and the permission to enter upon and cut into the streets, avenues, alleys, lanes, commons or public places shall be issued to the party of the second part before such work shall be begun.

SECTION 2. Upon filing such maps, plans and specifications and their approval, as aforesaid, the party of the second part may make the specified excavations and construct and lay the specified conduits, pipes, manholes and all necessary appurtenances for the distribution of steam for heating and other purposes, but the same shall be done with reasonable dispatch and with the least possible inconvenience to the public, and all such excavations and all such work, both in the original construction and in making any future extensions, repairs or improvements to the system, shall be done in such manner as not to interfere with any water or gas pipes, public or private sewer, or any underground conduit laid or constructed by said city or any authorized person, persons or corporations.

The party of the second part shall restore all streets, avenues, alleys, lanes, commons or public places where any excavations have been made by it to the original condition thereof, and so as to correspond with and conform to the portion of such streets, avenues, alleys, lanes, commons or public places adjoining such excavations, subject to the approval of the Board of Public Works.

SECTION 3. The party of the second part is hereby required to barricade any and all excavations made by it so as to render the same safe, and in case it is necessary for any excavation to remain unfilled or any embankment or obstruction to remain over night, the party of the second part shall place sufficient and suitable light or lights at and securely barricade such place or places.

SECTION 4. The party of the second part is hereby required to pay any and all damages to persons or property occasioned by reason of any fault or negligence of the agents, servants or employees of the said second party in the prosecution of the work herein contemplated, and in the event of a suit, or suits, against said city for damages for any injury, or injuries, sustained by any person, or persons, on account of the neglect of the said agents, servants or employees of said second party in the prosecution of the work herein contemplated, or for failure to keep the same in proper condition, or for any fault or neglect of the party of the second part, whenever the city shall notify the party of the second part of the pendency of any such suit, or suits, it shall be the duty of the party of the second part to defend such suit, or suits.

In case of the rendition of any judgment against said city in any such suit, or suits, the amount of such judgment, and the costs

thereof, shall be paid by the party of the second part, and in the event of its failure to pay the same such sum shall be recoverable by said city in any proper action against the party of the second part, and the record of any judgment rendered against the said city, together with the cost thereof, shall be deemed and taken to be the measure of damages in any such suit, or suits, and shall be conclusive evidence of the amount to be recovered against the party of the second part, to which shall be added a reasonable attorney's fee for the prosecution of any such action.

SECTION 5. The party of the second part shall be required to extend its system of heating mains and to furnish service to consumers when petitioned to do so by one or more freeholders, who in the aggregate will agree to take and pay for service supplying at least twelve hundred (1200) square feet of steam radiating surface for each two hundred (200) feet of pipe line necessary in the extension, and any such extension so petitioned for shall be made by the party of the second part within a reasonable time from the date of the filing of such petition and the execution of such agreement, or agreements.

SECTION 6. Steam shall be furnished by the party of the second part from September 15th to Mav 25th during each heating season and during the life of this contract whenever the outside temperature shall be sixty-five (65) degrees Fahrenheit, or lower, and the rate for such steam heating service shall not exceed thirty-five (35) cents per square foot of radiation per season; provided, that the sufficient radiation is set so as to maintain seventy-two (72) degrees temperature in the buildings with the radiators full of steam at one (1) pound pressure when the outside temperature is ten (10) degrees below zero.

If steam is sold by meter the rate shall not exceed the following schedule:

Up to 100,000 lbs. used in any month @ 65c per 1000 lbs.
100,000 to 200,000 lbs. used in any month @ 60c per 1000 lbs.
200,000 and over lbs. used in any month @ 50c per 1000 lbs.

Provided, however, that whenever the wholesale price of ——— slack (screenings) coal shall cost f. o. b. cars ———, ———, on yearly contract, less than one dollar and fifty cents ($1.50) per net ton the party of the second part shall reduce the rates hereinabove fixed one (1) cent per square foot of radiation for which heat is contracted on a flat-rate basis and two (2) cents per thousand (1000) pounds of steam used in any month on a meter basis, for each decrease in the cost of said coal of twenty-five (25) cents per net ton, and whenever the wholesale price of ——— slack (screenings) coal shall cost f. o. b. cars ———, ———, on yearly contract in excess of one dollar and fifty cents ($1.50) per net ton, then the party of the second part shall have the right to increase the rates hereinabove fixed, one (1) cent per square foot of radiation for which heat is contracted on a flat-rate basis and two (2) cents per thousand (1000) pounds of steam used in any month on a meter basis for each increase in the cost of said coal of twenty-five (25) cents per net ton, after having furnished the Common Council of said city satisfactory evidence of sufficient increase in the cost to warrant the increase in the price of heat as herein provided.

SECTION 7. The party of the second part shall within ——— months after the date of this contract commence the work herein contemplated and shall within ——— months from the date of the beginning of such work, unless prevented by unavoidable accidents or delays, be prepared to furnish to consumers steam for heating purposes, and upon the failure of the party of the second part to do so it shall forfeit all rights under this contract, and the same shall be null and void.

SECTION 8. Upon the completion of the initial system of conduits, pipes, manholes and other necessary appurtenances, the party of the second part shall furnish the party of the first part a map of said city drawn to scale, showing thereon a full and complete detail plan of its underground system, and upon making extensions and connections to the initial system, at any time, the said second party shall immediately revise or add to said map, showing thereon a full and complete detail plan of such additional extensions and connections.

SECTION 9. To the end that at the expiration of the period for which this grant is made there may be no doubt as to the respective rights of the parties hereto, it is agreed:

(a) If, at any time not less than three (3) months nor more than six (6) months before the expiration of said term, a new franchise and right to occupy the streets, avenues, alleys, lanes, commons and public places of said city, and supply steam for heating purposes, by means of pipes, conduits and appurtenances, shall not have been granted to the party of the second part, then the said city shall have the option to become the purchaser and the owner of all tangible property of the party of the second part by the payment to it of the fair cash value of such tangible property constituting the operating plant and system, and in case the said city, through its proper officers, and the party of the second part are unable to agree to the fair cash value, as aforesaid, of such property, the same shall be determined by a committee of three (3) persons, one of whom shall be chosen by the mayor of said city, one by the party of the second part, and the third by the two chosen as above, said third member of said committee to be a disinterested and reputable expert mechanical engineer, not residing in the State of ———, and not, at the time of his selection, in the employment of either of the parties of said contract, and the finding of the majority of such committee as to such value shall be binding on both the said city and the party of the second part, and the said city shall be bound to pay and the party of the second part shall be bound to accept such amount as the purchase price of such property; PROVIDED, that nothing herein contained shall be so construed as to compel the purchase by said city of such tangible property, or any part thereof, unless, by its officers, it shall elect to pay the cash value thereof, as aforesaid, appraised as hereinabove provided, and the Common Council of said city shall, at the proper time, have made the necessary appropriation for such purpose.

If the said committee of arbitration is selected and acts as above provided the expense thereof shall be equally divided between the party of the second part and said city.

(b) If, within three (3) months of the expiration of such period of twenty-five (25) years, this franchise shall not have been renewed or extended by a new contract duly ratified, and if said city shall not have exercised its rights to purchase the tangible property of the party of the second part, the city shall have the right, through its proper officers, to enter into a contract with and grant a franchise to another company, or corporation, to operate said plant upon such terms as may be fixed by such contract for a period commencing on the date of the expiration of the franchise hereby granted, and such company or corporation to which such new franchise may be granted may become the owner of the tangible property of the party of the second part, and have the right to take, hold and operate the same upon payment by it to the party of the second part the fair cash value thereof, as an operating plant and system, and in the event the party of the second part and such new company, or corporation, are unable to agree upon the fair cash value of such tangible property, then the same shall be determined by a committee of three persons to be chosen, one by each of the parties and the third by the two so chosen by the parties, such third party to be a disinterested reputable expert mechanical engineer, not residing in the State of ———, and not at the time of his selection in the employment of either of said companies, or corporations, and the decision of such committee, or a majority thereof, shall be final and binding on all parties.

The expense of such committee, including their compensation, shall be borne equally by the parties thereto.

(c) If, at the expiration of the term of twenty-five (25) years the City of ——— shall not have become the owner of said plant or system, and if the tangible property constituting such plant and system shall not have been sold and delivered to another corporation or company having first secured the right by a contract with the city to operate the same, and if this franchise shall not have been renewed or extended, as hereinbefore provided, then the city shall, through its proper officers, proceed to offer by public advertisement a new franchise for the operation of such plant and system for a term of years, which franchise shall be awarded to the bidder who, being solvent and responsible, offers the most favorable terms to the city and its citizens, and who will bind himself, themselves, or itself, as the case may be, to take the tangible property constituting such plant and system, and pay to the party of the second part the fair cash value thereof, as an operating plant, and if the parties cannot agree as to the fair cash value of such property, then the same shall be determined by a committee of three (3) persons, to be chosen, one by each of said parties and the third by the two so chosen by the parties, such third person to be a disinterested and reputable expert mechanical engineer, not residing in the State of ———, and not, at the time of his appointment, in the employment of either of said parties, and the decision of such committee, or a majority thereof, shall be final and binding on the parties thereto, and the expense of such committee, including compensation, shall be equally borne by the parties thereto.

SECTION 10. As security for the performance of the conditions of this contract on the part of the party of the second part, it shall, prior to beginning any construction work contemplated

under this contract, execute and file with the party of the first part, payable to the City of ———, ———, its bond in the sum of Five Thousand Dollars ($5,000.00), with surety to the approval of the party of the first part, which bond shall be conditioned for the faithful performance by the party of the second part of each and every stipulation and provision contained in this contract, and for carrying out all the terms and conditions hereof during the entire period covered hereby, and such bond shall be renewed at the end of each five (5) years' period, but which bond is to be and remain in full force until the bond in renewal thereof has been filed and approved, and the party of the first part hereby reserves the right to require a renewal of such bond at any time that it deems the surety thereon inadequate or when the same becomes impaired in amount by reason of just demands or claims against the same, or otherwise.

SECTION 11. It is understood and agreed that wherein in this contract the party of the first part is referred to and designated, it means The Board of Public Works of the City of ———, ———, or such officer, or officers, of the citv as may in the future be provided by statute to take the place of and perform the duties of such Board as now provided by law, and wherein in this contract the party of the second part is referred to and designated it means ———, or its successors and assigns.

SECTION 12. This contract to be in full force and effect after the passage of an ordinance by the Common Council of the City of ———, ———, ratifying the same, and the approval thereof by the mayor of said city, and finally upon the written acceptance of this contract and ordinance by the President and Secretary of ———, duly authorized and empowered by a majority of the stockholders of said ——— Company at a stockholders' meeting duly and regularly called for that purpose.

IN WITNESS WHEREOF, the parties to this instrument have executed the same in duplicate this day and date aforesaid.

.....,
.....,
.....,
Board of Public Works of the
City of ———, ———.
.....,
By.....,
President.

Attest:
.....,
Secretary.

FRANCHISES

Hot Water Franchise

An ordinance granting to THE ——— HEATING COMPANY, its successors and assigns, the right and privilege to lay, operate and maintain a system of pipes in the streets, avenues, alleys and public places in the City of ———, ———, for conveying hot water for heating and other purposes.

BE IT ORDAINED by the Common Council of the City of ———, ———:

SECTION 1. The right, privilege and franchise is hereby granted unto THE ——— ——— COMPANY, its successors and assigns, for the term of twenty-five years from the date of the passage and acceptance of this ordinance, to enter upon the streets, avenues, alleys and public places of the City of ———, ———, and therein to construct, lay, operate and maintain a system of pipes, mains, conductors and service pipes, with all necessary branches, cut-offs, manholes, appliances and other utilities for furnishing and conveying hot water, for heating and other purposes, to public and private consumers within said city.

SECTION 2. The right hereby granted shall vest in THE ——— ——— COMPANY, its successors and assigns, the Grantee herein, full power and license to make all necessary excavations for the purpose aforesaid, but the same shall be done with reasonable dispatch and with the least possible inconvenience to the public, and all such excavations and all such work shall be done in such manner as not to interfere with any water or gas pipe, public or private sewer, electric wire or any cable or other conduit for the same, now laid or constructed by said city, or any authorized person, persons or corporation. The Grantee herein, its successors and assigns, shall restore and repair all streets, alleys, sidewalks and public grounds where excavations are made by it, to the original condition thereof, and shall maintain such repairs to their original condition, and all damage done by reason of any such excavations shall be repaired by said Grantee, its successors and assigns, and so main-

tained, at its own cost without delay. The Grantee, its successors and assigns, in laying additional mains, repairing mains already laid, or to be hereafter laid, and in putting in service pipe and all other utilities, shall do so with diligence and dispatch, and as soon as the same have been completed it shall repair and restore such streets, alleys, sidewalks and public grounds wherein excavations have been made to their original condition, and so as to correspond with and conform to the portions of such streets, alleys, sidewalks and public grounds adjoining such excavations, and shall maintain the same as hereinbefore provided, subject to the approval of said Common Council. The surplus earth, if any remains from such excavations, shall be immediately removed by said Grantee, its successors and assigns, after said trenches and excavations are filled. Said Grantee, its successors and assigns, are hereby required to barricade any and all excavations made, so as to render the same safe; and in case it is necessary for any excavation or excavations to remain unfilled, or any embankment or embankments to remain over night, said Grantee, its successors or assigns, shall place a light or lights at and securely barricade such place or places.

Said Grantee, its successors and assigns, are hereby required to pay any and all damages either to persons or to property occasioned by reason of any fault or negligence of the Grantee, its successors or assigns, and by reason of any excavations or obstructions made or caused to be made by it at any time or place in said city; and in the event of suit, or suits, against said city for damages for any injury, or injuries, sustained by any person, or persons, on account of neglect of said Grantee, its successors or assigns, in the making of, or properly protecting said excavations or embankments so made, or for failure to keep the same in proper condition, or from any fault or neglect of the Grantee, its successors or assigns, whatever, said city shall notify said Grantee, its successors or assigns, of the pendency of such suit or suits, and it shall be the duty of said Grantee, its successors and assigns, to defend such suit, or suits, and in case any judgment, or judgments, be rendered against said city in any such suit, or suits, the amount of such judgment, or judgments, and costs thereon shall be paid by the Grantee, its successors or assigns, and in the event of the failure of the Grantee, its successors or assigns, to pay the same, and the city shall be compelled to bring suit against the said Grantee, its successors or assigns, for the reimbursement of any costs and damages, or either costs or damages, so incurred, the record of the judgment rendered against said city, together with the costs thereon, shall be deemed and taken to be the measure of damages in any such suit, and shall be conclusive evidence of the amount to be recovered against said Grantee, its successors or assigns, to which shall be added a reasonable attorney's fee for the prosecution of any such action.

SECTION 3. Heat shall be furnished by THE ——— ——— COMPANY, the Grantee herein, its successors or assigns, from September 15th to May 15th during each heating season whenever the outside temperature shall be sixty degrees or lower and the rate for service shall not exceed ——— per square foot per season, based upon the radiation being set so as to maintain seventy degrees in the buildings at zero outside, with circulating water en-

tering the building at one hundred and eighty degrees. *Provided,* however, that whenever the price of ——— mine run coal shall cost f. o. b. cars ———, ———, in excess of Two and Ten Hundredths Dollars ($2.10) per net ton, then the Grantee, its successors and assigns, shall have the right to increase the price hereinabove fixed one cent (1c) per square foot of radiation for each increase of twenty-five cents (25c) per net ton over said price of Two and Ten Hundredths Dollars ($2.10) per net ton, after giving due notice of any such increase to the Common Council of said city.

SECTION 4. The Grantee, its successors and assigns, shall construct its heating plant and shall have a system of street mains laid and in operation in at least the business portion of the city adjacent to the public square within twelve months from the date of the passage and acceptance of this ordinance, and shall thereafter be required to extend its system in each contiguous block or square whenever petitioned to do so by at least four freeholders within such contiguous block or square, who will agree to become patrons of said Grantee, its successors or assigns, and to take and pay for the heat at the prevailing rates for a period of three years from the date such petitioners' several properties are connected with the mains. *Provided,* that before the Grantee, its successors or assigns, shall be required to extend its mains and to furnish service into and through such contiguous blocks or squares, the said petitioners so agreeing to take service shall agree to take an amount aggregating at least two thousand square feet of radiating surface and to pay for the same for a period of three years from the date such service shall begin.

SECTION 5. In the construction of said system Grantee shall be compelled to lay and construct its system of street mains, service pipes and other apparatus with due conformity to the established grade lines of the streets, avenues, alleys and other public places, and all such system of street mains shall be laid at such depth as to give a covering over the top of the insulation of not less than two feet.

SECTION 6. The Grantee, its successors or assigns, shall extend its service pipes from its mains in the streets or alleys adjacent to the property of an applicant agreeing to become a patron of said Grantee to the property line of such applicant.

SECTION 7. Upon the completion of the initial system of street mains and service pipes said Grantee shall furnish said city a map of said city, drawn to scale, showing thereon a full and complete plan of its system of street mains, service pipes, manholes and other apparatus, and upon making further extensions and connections to the initial system, said Grantee shall immediately revise or add to the said map, showing thereon the additional mains, service pipes, manholes and other apparatus additionally constructed as aforesaid.

SECTION 8. Whenever said Grantee, its successors or assigns, shall desire to construct or lay, in any street, avenue, alley or other public grounds, any pipes, mains or other apparatus used for the construction of said heating system, said Grantee, its successors or assigns, shall make application therefor, in writing, to such officer

f said city as may be designated by the Common Council for such urpose, and secure a permit therefor, and when the work for hich such permit is secured and is issued shall have been com-leted, said Grantee, its successors or assigns, shall report such completion to said officer, and whenever said Grantee, its successors or assigns, shall desire to relay or repair any pipe, mains or other apparatus previously laid or constructed, pursuant to the right herein granted, the same shall be done under all the restrictions and subject to the same approval and conditions herein contained in relation to the original construction.

SECTION 9. Within ten days after the passage of this ordinance and the approval of the same, said Grantee, its successors or assigns, shall accept the same in writing, by filing a written acceptance thereof with the Clerk of said city, and within thirty days after the passage and approval thereof, the Grantee, its successors or assigns, shall file with the said Clerk a good and sufficient bond, subject to the approval of the Common Council of said city, in the penal sum of Ten Thousand Dollars ($10,000) conditional upon the full and faithful performance of all the obligations imposed upon the Grantee by this ordinance in the matter of the manner, mode and method of the construction of its proposed plant, and which shall insure to the said city a full compliance with the method of construction required by this ordinance, and the payment of all liabilities imposed thereby for any failure to comply therewith, and which bond shall be of such character as to give original jurisdiction to the courts of ——— ———, in the State of ———. When this ordinance shall have been so accepted, as hereinabove provided, and said bond shall have been so given as hereinabove provided, then this ordinance shall be deemed and considered a contract duly executed between the said City of ——— and the said THE ——— ——— COMPANY, its successors or assigns.

ORDAINED AND PASSED this ——— day of ———, 1906.

Attest:

.....,

Clerk, City of ———.

I, ———, Mayor of the City of ———, ———, have this the ——— day of ———, approved the annexed Ordinance.

.....,

Mayor, City of ———.

CHAPTER IX.

Building Equipment.

THIS is the part of the industry that affects the quality of our service. No matter how fine our station and pipe line operate, if there are any defects in building equipment our service will not be good. For that reason the author has devoted a chapter to this subject. It is very essential that the operators of a central station heating plant know this subject well. Many of the features of this subject are well known and these points will be purposely omitted because they do not belong exclusively to this subject. There are, however, many of them that are extremely vital and these points will be discussed.

In Chapter VII there are a few general notes of interest on this subject.

For the benefit of the "trouble man" it might be said that common sense, combined with a little perseverance, will locate the cause of most any trouble. Get it firmly in mind that the first thing necessary is to have sufficient pressure. Next, have each and every radiator hot, if desired. If these two conditions exist, either the amount of radiation is not sufficient or the construction of the building is at fault. The above will act as a guide to the location of the trouble.

How to Figure Radiation Required in a Building

Radiation required in square feet = the number of B. T. U. required by all heat losses, divided by the number of B. T. U. emitted per square foot of radiation per hour.

$$\text{Formula: } R = \frac{H}{h}$$

where R = sq. ft. of radiation (direct).
H = total heat needed per hour.
h = B. T. U. emitted per square feet per hour.

H = The total heat needed per hour. This is dependent upon two factors:

(1) The amount needed to heat the air in the room.

(2) The amount to overcome the cooling effect of the walls, windows, doors, ceilings and floors.

(1) The amount of heat needed to heat the air can be easily figured from the fact that 1 B. T. U. will heat, approximately, 50 cu. ft. of air 1° F.

In residence heating and in the average office and store buildings the following table gives the number of changes of air that can be expected, due to the ventilation that the occupants will require and usually get from opening and closing doors and windows.

Air Changes Per Hour

Halls	2 to 3
Living rooms	2 to 3
Dining rooms	1 to 2
Kitchens	2
Bedrooms	1
Sewing rooms	2
Second floor halls	1
Drug stores	3
Clothing stores	1
Jewelry stores	1
Grocery stores	1 to 2
Law offices	1
Doctor's offices	1 to 2
Dentist's offices	1 to 2

In rooms where the number of changes of air per hour is questionable, figure 1800 cu. ft. per hour per person and substitute this result for the cubic contents of the room.

Each occupant of a building will emit approximately 200 B. T. U. per hour in the form of radiated heat and each occupant requires approximately 1800 cu. ft. of air per hour.

(2) The amount of heat needed to overcome the cooling effect can be closely estimated by the table here shown.

The figures given for figuring the radiation in a building will be found reliable, but no set of rules or figures can give perfect results without some thought on the part of the engineer using them. A few suggestions are given herewith.

It is good practice to add for northern, northwestern, western and northeastern exposures, from 10% to 20% of the required radiation found from the preceding tables.

For rooms with 13 to 15-ft. ceilings, add 5 to 7%.

For rooms with 15 to 18-ft. ceilings, add 7 to 12%.

The reason for additional radiation required on account of exposure is easily appreciated.

The reason for more radiation being needed in rooms with high ceilings is owing to the fact that an average higher temperature is required to give the proper temperature at the breathing line. This is on account of the warmer air being at the ceiling. For this same reason more heat is lost due to the exposed walls being higher in temperature.

When the building is allowed to cool at night, add 10 to 15%.

When the building is allowed to become cold at night, add 15 to 30%.

When the building remains for a long period without heat, add 50%, when it is desired to heat the building rapidly.

One of the greatest heat losses is due to the leakage around the windows. The table given here for B. T. U. losses is for well-constructed windows, not stripped.

Heat emitted per square foot of radiation surface per hour is, of course, dependent upon the difference in temperature

Table Showing B. T. U. Emitted Per Square Foot Per Hour Through Various Building Materials.

Style of Partition	Difference in Temperature between Outside Air and Air in Room, in Degrees F.							
	30	40	50	60	70	80	90	100
Single window (good)	34	46	59	67	75	86	98	110
Single window (average)	36	48	61	73	86	98	110	123
Single skylight	30	41	52	63	73	83	94	105
Double skylight	18	24	30	37	43	49	55	62
Double window	22	30	36	42	51	59	66	72
Plate glass (set tight)	23	31	37	43	52	60	67	75
8-in. brick wall	14	18	23	27	32	36	41	46
Door (⅓ glass)	17	22	28	34	40	45	51	57
Plain door	12	16	20	24	28	32	26	40
12-in. brick wall	9	13	16	19	22	25	28	31
16-in. brick wall	8	10	13	13	18	21	23	26
20-in. brick wall	7	9	11	13	15	18	20	23
24-in. brick wall	5	7	8	10	13	15	18	21
30-in. brick wall	4	5	7	9	11	13	15	18
36-in. brick wall	3	4	6	7	8	9	11	13
8-in. brick wall, 3-in. air space	9	11	14	17	20	24	27	30
12-in. brick wall, 3-in. air space	8	10	13	15	18	22	25	28
16-in. brick wall, 3-in. air space	6	8	10	13	16	19	22	25
12-in. sandstone wall	16	20	25	28	31	34	37	41
16-in. sandstone wall	15	18	21	24	27	30	32	35
20-in. sandstone wall	13	15	18	22	25	28	30	33
24-in. sandstone wall	8	12	15	18	21	24	26	29
28-in. sandstone wall	9	11	14	16	19	22	25	27
36-in. sandstone wall	7	9	12	15	17	19	21	24
44-in. sandstone wall	5	8	10	12	14	16	18	20
12-in. limestone wall	18	22	26	30	34	38	41	44
16-in. limestone wall	14	18	22	26	30	34	38	40
20-in. limestone wall	15	19	22	25	28	30	33	35
24-in. limestone wall	12	14	18	21	24	27	30	33
28-in. limestone wall	9	13	16	19	22	25	28	31
36-in. limestone wall	8	11	14	16	19	21	24	27
44-in. limestone wall	7	9	12	14	16	18	20	22
1½-in. pine plank	8	12	15	18	21	24	27	30
2-in. pine plank	8	10	13	16	18	20	22	24
2½-in. pine plank	7	9	11	14	16	18	20	22
3-in. pine plank	5	8	10	12	14	16	18	20
Sheathing and clapboards	12	14	16	18	20	22	24	26
Sheathing paper and clapboards	8	10	12	14	16	18	20	22
L. and P. partition (one side)	18	20	23	25	28	32	36	40
L. and P. partition (both sides)	10	13	16	19	22	25	28	31
L. and P. ceiling (one side)	18	20	23	25	28	32	36	40
¾-in. floor, no plaster below	13	16	19	22	25	28	31	34
¾-in. floor, L. and P. below	8	10	13	16	19	22	25	28
1⅛-in. double floor, no plaster	9	11	14	17	20	23	25	27
1⅛-in. double floor, L. and P. below	5	7	9	11	13	15	17	19
Average frame	15	18	21	24	26	28	31	33
Average frame, back plastered	14	17	20	22	24	26	28	30
Average red brick, back plastered	14	17	20	22	24	26	28	30

of the heating medium (steam or water) and the air in the room. This ratio changes somewhat as the difference increases, but the following formula will be sufficiently correct for most conditions:

$$h = (T\text{-}t) \times 1.65.$$

where h is heat emitted per hour in B. T. U.
T = temperature of heating medium.
t = temperature of room.

For example:

Temperature of room = 70° F.
Temperature of water = 180° F.
(180—70) = 110 x 1.65 = 181.5 B. T. U.
Or, with temperature of room = 70° F.
Temperature of steam at 1 lb. = 216° F.
(216—70) = 146 x 1.65 = 241 B. T. U. emitted per sq. ft. of radiation.

Temperature of radiators at given pressures can be ob-

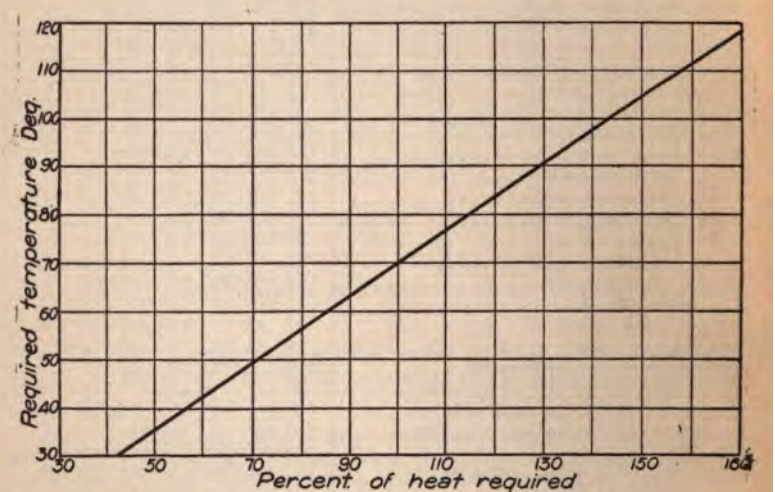


FIG. 31—CURVE SHOWING PERCENTAGE OF DIRECT RADIATION REQUIRED FOR DIFFERENT TEMPERATURES, BASED UPON 70° F. BEING 100%

tained from any reliable steam table, but for convenience are given here.

Steam Pressure in Pounds, Gauge.	Temperatures in Degrees F.
40	287
30	275
25	267
20	259
15	250
10	240
5	227
3	222
2	219
1	216
0	212
— 5½	200
—10	190
—13	180
—18	170
—19	160
—21	150

Values for "h" usually used by the author when inside temperature is 70° F.

B. T. U. emitted:

Steam, 5 lbs., 250 B. T. U.
Vapor, 0 lbs., 220 B. T. U.
Water, 170° F., central station, 165 B. T. U.
Water, 160° F., gravity, 148 B. T. U.

For example, we will consider a room as follows: (Example, No. 1.)

Outside temperature = —10° F.
Room temperature = 70° F.
Good frame wall B. P.
Good window construction.
Room above, heated.
Tight basement below, with rugs and double floor.

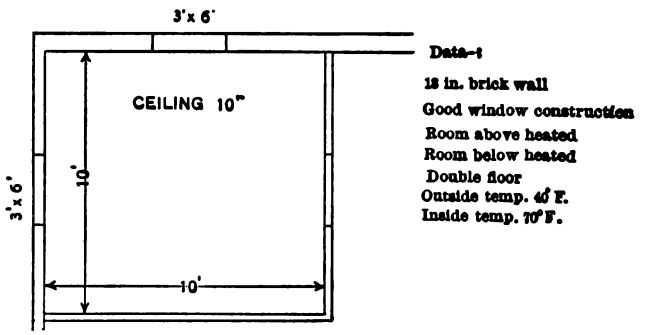


FIG. 32—TYPICAL ROOM IN 10-ROOM HOUSE AS USED IN CALCULATIONS

To figure this room for direction radiation:

Air to be heated 1 change of air per hour = 10 x 10 x 10 = 1000 cu. ft.

$$\frac{1000 \times 80}{50} = 1600 \text{ B. T. U.}$$

Where 80° is degrees F., air must be heated (—10 to 70).

Glass surface requires $2(3 \times 6) \times 86 =$	3096 B. T. U.
Wall surface = ((20 x 10)—36) 26 =	4264 B. T. U.
Add for exposure	896 B. T. U.
Total.....	9856 B. T. U.

$\frac{9856}{250}$ = steam = 39 sq. ft. Set 40 sq. ft.

$\frac{9856}{220}$ = vapor = 44 sq. ft. Set 45 sq. ft.

$\frac{9856}{165}$ = central station water = 59 sq. ft. Set 60 sq. ft.

$\frac{9856}{150}$ = gravity water = 65 sq. ft. Set 65 sq. ft.

In central station steam heating, in addition to the direct radiation, a cooling coil with a surface equal to 20% of the direct radiation should be set.

In central station vapor heating, this cooling coil can be eliminated, but we must increase each direct radiator 20% so as to have the cooling coil in each radiator.

Example No. 2:

Outside temperature = 0° F.		
Windows—fairly loose.		
Partition—L. and P., both sides.		
Room underneath is heated.		
Room overhead is a warm attic.		
Cubic contents = 1000 cu. ft.	= 1600	B. T. U.
Exposed wall = 164 x 22	= 3608	B. T. U.
Glass = 36 x 86	= 3096	B. T. U.
Cold partition = 100 x 10	= 1000	B. T. U.
	9304	B. T. U.
Add for exposure	930	B. T. U.
Total	10,234	B. T. U.

Example No. 3:

Same sized windows.

Same sized room.

Southeastern exposure.

Room underneath is cold, no heat, with 20° F., as minimum temperature.

Room overhead is cold, 30° F. as minimum temperature.

Surrounding rooms, heated.

Exposed walls, 12 in. limestone, plastered.

Ceiling, ordinary lath and plastered, with floor above.

Floor, ⅞ in. double flooring.

Owing to use of room, three changes of air per hour can be expected.

Average windows.
Outside temperature = 20° F.
Room temperature = 80° F.

$$\text{Cubic contents} = \frac{1000 \times 100}{50} \times 3 = 6000 \text{ B. T. U.}$$

Glass = 2(3 x 6) = 36 x 123	=	4428 B. T. U.
Exposed wall (200—36) x 44	=	7216 B. T. U.
Floor, 10 x 10 x 27	=	2700 B. T. U.
Ceiling, 10 x 10 x 31	=	3100 B. T. U.
Total.....		23,444 B. T. U.

The following data sheet will be found a great help in arranging, figuring and filing information relative to the radiation required. In addition to this sheet there should be a plan of the building, having on it all the dimensions of rooms, windows, etc., and any other information necessary to convey a complete analysis of the conditions. Measurements of windows should be from outside to outside of window frame. The number of changes of air per hour necessary depend upon the use of the room and the number of occupants. An old rule and not necessarily correct, but good practice, is to figure 1800 cu. ft. of air per hour per person.

Radiation Data Sheet

No.....

Name of owner..... Tenant.....

Location of building.....

Room No. .... (Name) .... Number of changes of air....

Cubic contents.
Glass surface.
Exposed wall.
Ceiling.
Floor.
Partitions.

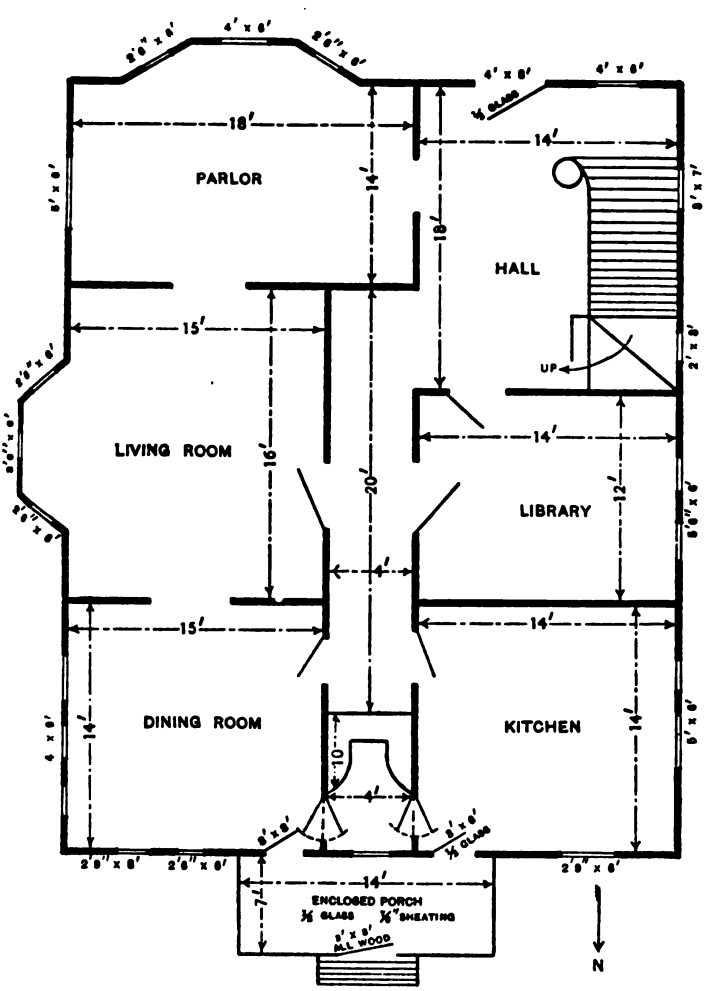


FIG. 33—TYPICAL HOUSE PLAN FOR USE WITH RADIATION DATA SHEET

Exposure.
Unusual conditions.
Total B. T. U.....
Square feet .....Radiation.
Name, John Doe.
Location, 181 East 8th street.

Data:

Ceiling = 10 ft.
Ceiling porch = 12 ft.
Wall = ⅞ in. clap-board, paper sheeting, 2 in. x 4 in. studding and lathed and plastered.
Windows, good.
Cellar, under entire house, 8 ft. ceiling and tight.
Floor overhead, all heated.
No heat in enclosed porch.

The two maps on page 147 show the average and minimum temperatures as recorded by the U. S. Weather Bureau. The average is taken for the usual heating season from October 1 to May 1.

In estimating the amount of radiation required in a building, the minimum temperature should be noted, but an allowance made for the fact that the figures there given are the extreme.

For example, the minimum temperature for New York City is 6° F. below zero, but, as a matter of fact, zero has been very unusual in New York City for some time.

The author usually deducts 10° from these figures and then assumes the nearest number divisable by 5 as the minimum temperature. For example, Denver (— 29° less 10° = — 19°) 20° below zero would be the extreme to figure against. Chicago would be 15° below zero, Pittsburg, 10° below zero.

The average temperatures are given for reference, so that the heating seasons in different localities can be compared.

Compiled from the United States Weather Bureau Reports

FIG. 34—MAP OF THE UNITED STATES SHOWING IN EACH STATE THE LOWEST TEMPERATURE RECORDED

FIG. 35—MAP OF THE UNITED STATES SHOWING IN EACH STATE THE AVERAGE TEMPERATURE OF THE USUAL HEATING SEASON FROM OCTOBER 1 TO MAY 1

Wind Effect on Heating

AIR LEAKAGE AROUND WINDOWS AND OTHER OPENINGS

One of the uncertain factors in heating is the effect that wind produces, not only in driving the cold air in, but also in causing a suction which draws the warm air out of a building. This effect takes place in and through the walls, as well as through the window slots. In the radiation tables given in this book the average effect of wind on the average construction has been considered, but there are often extreme cases in which this loss of heat should be carefully considered by the engineer.

Window strips are a well-known and effective remedy for the leakage around windows and, in the majority of cases, are fuel savers of no mean account. The use of strips stops a great deal of cold air and dust from entering the room during the heating season, as well as keeping out hot air and dust in the summer, and the author recommends their use where the inleakage is not desirable or not needed. There are cases, however, where the additional fresh air is needed for ventilating purposes and then it is better to set additional radiation to heat this air than to restrict the supply of fresh air. If the air is laden with dust and smoke or other undesirable particles, other means of ventilation should be provided and the air washed or in some way purified before being allowed to enter the room.

The exact amount of heat saved by the use of window strips is a variable quantity due to the fact that it is seldom that conditions are always the same. The location of a building has a decided influence on the saving; for example: a building located on a hill and exposed to the strong winds will lose more heat through the window slots than a building more protected by its surroundings.

As a general rule, the author believes that it is good practice to install window strips and, if ventilation is needed, secure it by opening or closing windows. This arrangement allows one to control the amount of air needed and materially helps in regulating the heat.

Location of Direct Radiation

The central station heating engineer should be thoroughly conversant with the best practice in locating his radiators, as well as to know how to figure the amount of radiation necessary. The owner of the building or his wife and family will, of course, complain about giving up the necessary space and, in many cases, the architect will be as hard to convince as the rest of those interested that upon the location of radiators much depends, and the author hopes this book will help some heating man solve the problem, at least, as far as the location of the correct position is concerned.

From the accompanying sketch it will be noticed that there are five positions on the walls where the radiator could be set, A, B, C, D and E.

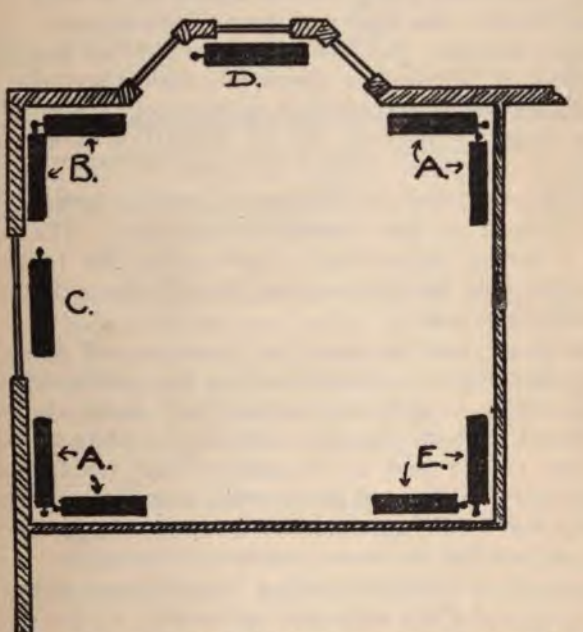


FIG. 36—FIVE POSSIBLE LOCATIONS OF A DIRECT RADIATOR IN A ROOM

In commenting upon this subject the author has taken into consideration that any window radiation would be 14 in. to 20 in. and that the wall radiators would be 32 in. to 45 in. high. It is a well-known fact that the shorter the length of the section, the more heat will be emitted per inch of height from convection, other things being equal. But the author has found that, with window radiation, other things are never equal, unless the window radiation is taken away from the window and set along a wall, for the reason that the circulation of the air in the room causes the heat to be given off by the radiator and, if you stop the velocity of circulation of the air, you materially affect the efficiency of the radiating surface.

Consider, for an example, that a radiator is placed under the window, as in sketch (Fig. 37), you will notice that the tendency of the air is to rise from the radiator to the ceiling, then pass along the ceiling to the interior wall and thence down to the floor and over to the radiator, as shown by heavy arrows. But the leakage of cold air and the cooling effect of the window check this direction and a circulation, as shown by dotted lines, is obtained which, of course, is not desirable, because the air circulation is not as rapid nor is it complete. There are parts of the room which receive no circulation whatsoever and, consequently, receive little or no heat except by radiation. The temperature of the air immediately surrounding the radiator will be higher and, for that reason, the efficiency of the radiator will be lowered.

The exact amount that the radiator will lose in efficiency is difficult to determine, but the author experienced a case where a 96 sq. ft. radiator, set under the window, would not heat the room above 66° F., while an 80 sq. ft. radiator, placed just at the side of the window and not over 3 ft. from the unexposed wall, heated the room to 73° F. with the incoming water at the same temperature, 170°, and, practically, the same outside temperature.

The author thinks, therefore, that "under the window" is not a good place to locate radiation.

We will next consider location "B," which is really centralized on the exposed wall, but away from the windows.

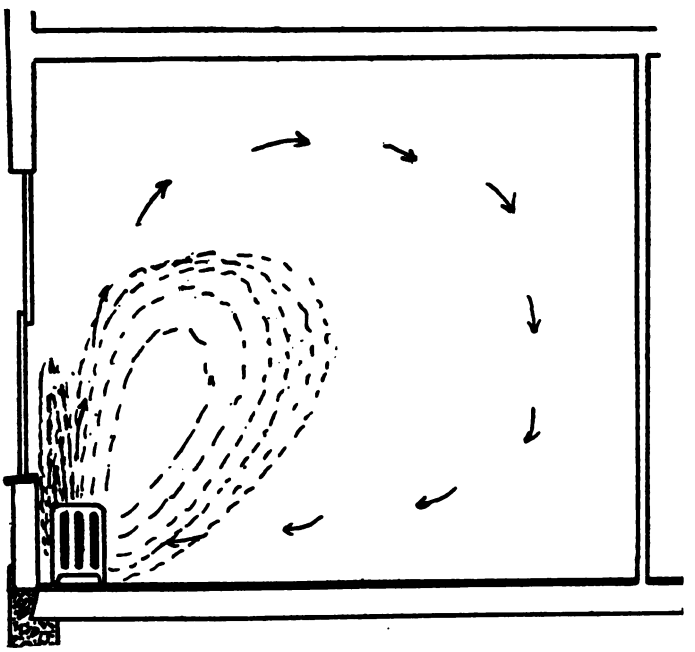


FIG. 37—COURSE OF AIR FROM DIRECT RADIATOR LOCATED IN FRONT OF WINDOW

In this case the cold air from the windows seems to drop to the floor and join the air going to the radiator and, after passing through the radiator and being warmed, it rises to the ceiling and spreads over the room, cooling and falling to the floor and thence returning to the radiator. This makes a very desirable condition and is considered by the author a good location.

In location "A," the radiator is divided into two radiators set at right angles to the exposed walls and on the unexposed walls but near the exposed walls. In this case nearly the same effect is secured and, in some cases, a better circulation of the air is secured. The cooling surfaces of the walls and windows cause the air to fall and mix with the warmer air coming from the unexposed part

of the room and it then circulates rapidly through the radiator and to the ceiling. This the author considers a good location. The second position of "A," that is, on the exposed walls, as shown is also a good location.

Location "E" is next to be considered and is probably exactly opposite from the usual way of locating radiators. In this case the cooling effect of the walls materially aids the air circulation, but the leakage from the windows must travel entirely across the room before being heated. It does, of course, mingle with the warm air to a certain extent. This location gives the best circulation of any position, but the windows should be made tight and probably 5% to 10% more radiation should be installed, but it gives a much more even temperature in the room if the leakage of air around the windows is stopped.

It is next to impossible to heat any room with bad and loose window construction and all central heating companies furnishing heat, either by meter or flat rate, should induce their consumers to keep the windows in good repair. It will be cheaper for the consumer, as well as much more pleasant, and, consequently, much more pleasant for the company.

There is, however, one important point that should be mentioned at this time. Never, for the sake of diminishing the heat bills, allow the consumer to fix his windows so tight that he will not get sufficient fresh air; and, another point, always set sufficient radiation to allow the proper number of changes of air per hour, even if the windows are tight, for nine people out ten will open the windows or doors so as to get sufficient fresh air and they should be allowed this privilege.

The author claims that often there is an excessive amount of air that enters our buildings and this excess is a waste of heat and should be kept at a minimum. On the other hand, the doctor's bills, necessitated by a cold, la grippe, pneumonia and, oftentimes, tuberculosis, will amount to a great deal more, even in dollars and cents, than the wasted heat. It is for this reason that the heating engineer should use extreme care in designing the heating

system for a building. It is far more important than the lighting in that it affects the health of the occupants.

One of the strong points in favor of central station heating is its cleanliness, and the fact that it reduces the dust and dirt, and allows us the use of more pure air for ventilation.

Decoration of Radiators.

From elaborate and careful tests it has been proven that the decoration of radiators has a considerable effect upon the heat given off per square foot of surface.

An interesting test was conducted by Prof. Allen at the University of Michigan, in which it was learned that the last coat of covering was the one that affected the result, no matter if there were a half-dozen other coats under the last one. The result of this test was given by Prof. Allen at the 1911 meeting of the National District Heating Association. The following is condensed from his paper:

Effect of Paint on Efficiency of Direct Radiators.

Condition of Surface.	Efficiency.
Plain as received from factory.....	1.00
Painted with copper bronze	.76
Painted with terra cotta enamel.....	1.04
Painted with aluminum bronze	.73
Painted with snow white enamel.....	1.01
Painted with bronze green enamel.....	.99
Painted with maroon gloss japan.....	.99
Painted with white zinc paint.....	1.01

Temperature Control.

This method of heat regulation has become so universally adopted that it seems unnecessary to explain the method employed to regulate the temperature. The motive power used to operate the system is generally compressed air, which is controlled by a machine called a thermostat, or in some devices the thermostat is sufficiently strong to create enough power within itself to cause any movement of the valve necessary to operate the system.

In a compressed air system the air is usually supplied by the heating plant and piped at the required pressure to the different buildings.

The self-contained machines do not require any outside connection. The advantage of one system or make of regulation over any other depends upon the perfection of the machine as to its ability to operate accurately and continuously without trouble and without frequent attention.

Some of the advantages of temperature control have been mentioned in the chapter on "Rates." It is shown there that, theoretically, this method of control will save an average of 50% of the heat consumption of a building, but as a matter of fact 30% is about the amount of heat it would save under actual practice. There have been many engineers who originally could not see any advantage to be gained by a company installing the system, but most of these have been converted and only after having it proved to them that mechanical control is more accurate than the average human control.

It is necessary for the occupants of a building to have sufficient fresh air, and with temperature control this can be accomplished very nicely without causing any undue waste of heat. If the temperature is maintained at an even degree there will not be a great temptation to open the windows when fresh air is needed. If it is needed, it should be obtained at any cost or any waste of heat. From the point of view of the consumer, there is nothing that will give more comfort than this method of control.

A heating plant operating on a flat rate without temperature regulation must charge 6 to 8c. more per square foot per season for hot water service and from 10 to 13c. per square foot more for steam service. On a meter basis, of course, the company need not care so much, but the consumer will be better satisfied and, for that reason, the company should see to it that temperature control is installed for them if they ask it.

As shown in the chapter on "Operation," the amount of pumpage in a hot water plant is materially cut down by using temperature control, and the same reasoning applies to a steam plant.

If 30% of the heat is saved, a given sized pipe line will handle 30% more business. In the case of either a steam or a water plant, thermostatic control successfully helps the distribution of the heating medium. When a building is sufficiently heated, it is automatically shut off and the supply of heat is stopped and other buildings on the line will receive a more abundant supply until they are heated. When the control valve opens up it opens just far enough to allow the required amount of heat to enter and no more.

Pipe Covering.

The covering of the pipe and fittings in a building are absolutely necessary to economical operation. Pipes and fittings should be covered with a good grade of covering and well covered with at least 1 in. of same. If not covered, the exposed surface should be paid for as radiating surface. In this connection it is interesting to note that a wrought pipe, lying horizontal in a basement, where the temperature is seldom over 55° or 60° F., will emit about 33⅓% more heat per square foot of surface than a cast-iron radiator will give off. For this reason one-third more should be charged for this service than for regular radiation. There are a few cases that have come to the author's attention where the space between the ground and the first floor was sealed tight and most all of the heat was transmitted through the floor and helped out the balance of the house, but these cases are few and far between, and, even then, it would have been more economical to cover these pipes.

The management of a heating plant should insist on this point.

The author has seen the heat consumption reduced one-third by covering the pipes and fittings under the floor of a cottage without a basement.

Miscellaneous Data

Weights and Measures

AVOIRDUPOIS OR COMMERCIAL WEIGHT

UNITED STATES AND BRITISH.

Grains.	Ounces.	Pounds.	Hundred-weight.	Gross Tons.
1.	0.002286	0.000143	0.00000128	0.000000176
437.5	1.	0.0625	0.00055804	0.00002790
7000.	16.	1.	0.0089286	0.0004464
784000.	1792.	112.	1.	0.05
15680000.	35840.	2240.	20.	1.

1 pound avoirdupois = 1.215278 lbs. troy.
1 net ton = 2000 lbs. = 0.892857 gross tons.
1 pound troy = 0.82286 lbs. avoirdupois.

LINEAR MEASURE

UNITED STATES AND BRITISH.

Inches.	Feet.	Yards.	Rods.	Miles.
1.	0.08333	0.02778	0.0050505	0.00001578
12.	1.	0.33333	0.0606061	0.00018939
36.	3.	1.	0.1818182	0.00056818
198.	16.5	5.5	1.	0.003125
63360.	5280.	1760.	320.	1.

GUNTER'S CHAIN MEASURE

Used in Surveying

1 link = 7.92 in. = 0.01 chain = 0.000125 mile.
1 chain = 100 links = 66 ft. = 4 rods = 0.0125 mile.
1 mile = 80 chains = 8000 links.

SQUARE OR SURFACE MEASURE

UNITED STATES AND BRITISH.

Square Inches.	Square Feet.	Square Yards	Square Rods.	Acres.	Square Miles.
1	0.006944	0.0007716	.....	.....	.....
144	1.	0.111111	.....	.....	.....
1296	9.	1.	0.08306	0.0002066	.....
39204	272.25	30.25	1.	0.00625	0.00000977
6272640	43560.	4840.	160.	1.	0.0015625
	27878400.	3097600.	102400.	640.	1.

1 acre = 10 square chains.

CUBIC MEASURE

1728 cubic inches = 1 cubic foot.
27 cubic feet = 1 cu. yard = 46656 cu. inches.
1 cord wood = 4 ft. × 4. ft. × 8 ft. = 128 cu. ft.
1 perch of masonry = 16.5 ft. × 1.5 ft. × 1 ft. = 24.75 cu. ft., but is generally assumed to be 25 cu. ft.

DRY MEASURE

UNITED STATES ONLY.

Struck Bush.	Pecks.	Quarts.	Pints.	Gallons.	Cubic Inch.
1	4	32.	64	8.	2150.4
	1	8.	16	2.	537.6
		1.	2	0.25	67.2
		0.5	1	0.125	33.6
		4.	8	1.	268.8

The United States standard unit for dry measure is the old English Winchester bushel, which contains 2150.42 cu. in., or 1.2445 cu. ft.

The heaped bushel, the cone of which is 6 in. above the brim of the measure, contains 2747.7 cu. in.

In New York a bushel contains 2218.2 cu. in., or 1.2837 cu. ft., which is the same as the Imperial bushel of England. Thirty-three English or Imperial bushels are equal to 34.04 Winchester or United States bushels.

LIQUID MEASURE

UNITED STATES ONLY.

Cubic Inch.	Pints.	Quarts.	Gallons.	Barrels.	Hogs-head.
28.875	1.	0.5	0.125	0.003968	
57.75	2.	1.	0.25	0.007937	
231.	8.	4.	1.	0.031746	
7276.5	252.	126.	31.5	1.	0.5
14553.0	504.	252.	63.	2.	1.

The British Imperial gallon = 1.20032 U. S. gallons.

The United States standard unit for liquid measure is the gallon = 231 cu. in. = 8.33888 pounds, avoirdupois, of distilled water at 62° F.

The English standard is the Imperial gallon = 277.2738 cu. in. = 10 pounds, avoirdupois, of distilled water at 62° F.

NAUTICAL MEASURE

A knot or nautical mile = 1.1527 statute miles = 6086 feet = length of a minute of longitude of the earth at the equator, at the level of sea, as determined by U. S. Coast Survey.

3 knots = 1 league.

SHIPPING MEASURE

1 Register ton = 100 cubic feet.
1 U. S. Shipping ton = 40 cubic feet.
1 British Shipping ton = 42 cubic feet.

MEASURE OF WORK AND POWER

A unit of work = one foot pound, or a pressure of one pound exerted through a space of one foot.

A British Thermal unit = 778 foot pounds.

A Horse Power =
- 33,000 foot pounds per minute.
- 550 foot pounds per second.
- 42.42 heat units per minute.
- 0.707 heat units per second.
- 746 watts.
- 0.746 kilowatt.

THE METRIC SYSTEM OF WEIGHTS AND MEASURES

In the **Metric System,** the **Meter** is the base of all the weights and measures which it employs.

The **Meter** is the primary unit of length and was intended to be one-ten millionth part of the distance, measured on a meridian of the earth, from the equator to the pole, and equals about 39.37 in.

Upon the Meter are based the following primary units: the **Square Meter,** the **Are,** the **Cubic Meter** or **Stere,** the **Liter** and the **Gram.**

The **Square Meter** or **Centare** is the unit of measure for small surfaces.

The **Are** is the unit of land measure; this is a square whose side is ten meters in length, and which contains one hundred square meters or centares.

The **Cubic Meter,** or **Stere,** is the unit of volume; this is a cube whose edge is one meter in length.

The **Liter** is the unit of capacity; this is the capacity of a cube whose edge is one-tenth of a meter—that is, one decimeter in length.

The **Gram** is the unit of weight; this is the weight of distilled water at 4° C., contained in a cube whose edge is the one-hundredth part of a meter.

From these primary units the higher and lower orders of units are derived decimally as follows:

SCHEME OF THE WEIGHTS AND MEASURES OF THE METRIC SYSTEM

Ratios	Lengths	Surfaces	Volumes	Weights
1,000,000.	....	....	.....	Millier, or Tonneau
100,000.	....	....	.....	Quintal
10,000.	Myr'iameter	....	.....	Myr'iagram
1,000.	Kil'ometer	.....	Kil'oliter	Kil'ogram, or Kilo
100.	Hec'tometer	Hect'are	Hec'toliter	Hec'togram
10.	Dek'ameter	.....	Dek'aliter	Dek'agram
1.	Meter	Are	Li'ter	Gram
0.1	Dec'imeter	.....	Dec'iliter	Dec'igram
0.01	Cen'timeter	Cen'tare	Cen'tiliter	Cen'tigram
0.001	Mil'limeter	....	Mil'liliter	Mil'ligram

It will be seen from this table that 10 millimeters equal 1 centimeter, 10 centimeters equal 1 decimeter, and so on.

Multiples and sub-multiples of the units, meter, liter and gram are expressed by the prefixes:

Deka = 10	Deci = 0.1
Hecto = 100	Centi = 0.01
Kilo = 1000	Milli = 0.001

ABBREVIATIONS COMMONLY IN USE

mm, millimeter,	m^2, square meter,
cm, centimeter,	km^2 " kilometer,
dm, decimeter,	mm^3, cubic millimeter,
m, meter,	cm^3 } " centimeter,
km, kilometer,	cc }
mm^2, square millimeter,	dm^3, " decimeter,
cm^2, " centimeter,	m^3, " meter,
dm^2, " decimeter,	....

A, are; ha, hectare; cl, centileter; l, liter, hl., hectoliter; s, stere; mg, milligram; cg, centigram; g, gram, kg, kilo or kilogram; t, tonneau, or metric ton.

Metric and U. S. Conversion Table

MEASURES OF LENGTH

Metric to U. S.

1 millimeter = 0.03937 inch.
1 centimeter = 0.3937 inch.
1 meter = 39.37 inches.
1 meter = 3.2808 feet.
1 kilometer = 0.6214 mile.

U. S. to Metric

1 inch = 25.4 millimeters.
1 inch = 2.54 centimeters.
1 inch = 0.254 meter.
1 foot = 0.3048 meter.
1 mile = 1.609 kilometers.

MEASURES OF SURFACE

Metric to U. S.

1 sq. millimeter = 0.00155 sq. inch.
1 sq. centimeter = 0.155 sq. inch.
1 sq. meter = 10.764 sq. feet.
1 sq. meter = 1.196 sq. yards.
1 hectare = 2.471 acres.
1 hectare = 0.00386 sq. mile.
1 sq. kilometer = 0.3861 sq. mile.

U. S. to Metric

1 sq. inch = 645.14 sq. millimeters.
1 sq. inch = 6.452 sq. centimeters.
1 sq. foot = 0.0929 sq. meter.
1 sq. yard = 0.8361 sq. meter.
1 acre = 0.4047 hectares.
1 sq. mile = 259.00 hectares
1 sq. mile = 2.59 sq. kilometers.

MEASURES OF VOLUME AND CAPACITY

Metric to U. S.

1 cu. centimeter = 0.061 cu. inch.
1 cu. meter = 35.316 cu. feet.
1 cu. meter = 1.308 cu. yards.
1 liter = 1 cu. decimeter = 61.023 cu. in.

LIQUID MEASURE

1 liter = 1.0567 quarts.
1 liter = 0.2642 gallon.
1 cu. meter = 264.17 gallons.

DRY MEASURE

1 liter = 0.908 quart.
1 hectoliter = 2.8375 bushels.

U. S. to Metric

1 cu. inch = 16.39 cu. centimeters.
1 cu. foot = 0.0283 cu. meter.
1 cu. yard = 0.7645 cu. meter.
1 cu. foot = 28.32 liters.

LIQUID MEASURE

1 quart = 0.9463 liter.
1 gallon = 3.7854 liters.
1 gallon = 0.0038 cu. meter.

DRY MEASURE

1 quart = 1.1013 liters.
1 bushel = 0.3524 hectoliter.

WEIGHTS

Metric to U. S.

1 milligram = 0.0154 grain.
1 gram = 15.432 grains.
1 kilogram = 2.2046 lbs. (avoir.)
1 metric ton = 1.1023 net tons.
1 metric ton = 0.9842 gross ton.

U. S. to Metric

1 grain	=	64.80 milligrams.
1 grain	=	0.0648 gram.
1 lb. (avoir.)	=	0.4536 kilogram.
1 net ton	=	0.9076 metric ton.
1 gross ton	=	1.0161 metric tons.

COMPOUND UNITS

Metric to United States

1 kilogram per meter	=	0.6720 lbs. per foot.
1 kilogram per sq. centimeter	=	14.233 lbs. per sq. in.
1 kilogram per sq. meter	=	0.2048 lbs. per sq. ft.
1 kilogram per cubic meter	=	0.0624 lbs. per cu. ft.
1 kilogram-meter	=	7.233 foot pounds.
1 cheval vapeur (metric H. P.)	=	0.986 horse-power.
1 kilo. watt	=	1.340 horse-power.
1 kilo. per cheval	=	2.235 lbs. per H. P.

United States to Metric.

1 lb. per foot	=	1.4882 kilograms per meter.
1 lb. per sq. inch	=	0.0703 kilo. per sq. centimeter.
1 lb. per sq. foot	=	4.8825 kilograms per sq. meter
1 lb. per cubic foot	=	16.0192 kilo. per cubic meter.
1 foot pound	=	0.1383 kilogram-meter.
1 horse-power	=	1.014 cheval vapeur (met.H.P.)
1 horse-power	=	0.746 kilo watt.
1 lb. per horse-power	=	0.447 kilos per cheval.

HEAT INTENSITY

$$\text{Temp. Centigrade} = (\text{temp. Fahr.} - 32°)\ \frac{5}{9}$$

$$\text{Temp. Fahrenheit} = (\text{temp. C.} \times \frac{9}{5}) + 32°.$$

HEAT QUANTITY

A kilogram calorie	=	3.968 British thermal units.
A pound caloric	=	1.8 British thermal units.
A British thermal unit	=	0.252 kilogram calorie.
A British thermal unit	=	0.555 pound caloric.

Mechanical, Electrical and Heat Equivalents (Continued)

Unit.	Equivalent Value in Other Units.
1 Heat unit. =	1,055 watt seconds. 778 ft.-lbs. 107.6 kilogram metres. 0.000293 K. W. hour. 0.000393 H. P. hour. 0.0000688 lb. carbon oxidized. 0.001036 lb. water evaporated from and at 212° F.
1 Heat-unit. per Sq. ft. per min. =	0.122 watt per square inch. 0.0176 K. W. per square foot. 0.0236 H. P. per square foot.
1 Kilogram Metre =	7.233 ft.-lbs. 0.00000365 H. P. hour. 0.00000272 K. W. hour. 0.0093 heat-units.
1 lb. Carbon Oxidized with perfect Efficiency =	14,544 heat-units. 1.11 lb. Anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 21 cubic feet illuminating-gas. 4.26 K. W. hours. 5.71 H. P. hours. 11,315,000 ft.-lbs. 15 lbs. of water evaporated from and at 212° F.
1 lb. Water Evaporated from and at 212° F. =	0.283 K. W. hour. 0.379 H. P. hour. 965.7 heat-units. 103,900 k. g. m. 1,019,000 joules. 751,300 ft.-lbs. 0.0664 lb. of carbon oxidized.

Mechanical, Electrical and Heat Equivalents (Continued)

(H. W. LEONARD.)

UNIT.	EQUIVALENT VALUE IN OTHER UNITS
1 K. W. Hour =	1,000 watt hours. 1.34 horse-power hours. 2,654,200 ft.-lbs. 3,600,000 joules. 3,412 heat units. 367,000 kilogram metres. 0.235 lb. carbon oxidized with perfect efficiency. 3.53 lbs. water evaporated from and at 212° F. 23.75 lbs. of water raised from 62° to 212° F.
1 H. P. Hour =	0.746 K. W. hours. 1,980,000 ft.-lbs. 2,545 heat-units. 273,740 k. g. m. 0.175 lb. carbon oxidized with perfect efficiency. 2.64 lbs. water evaporated from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 Kilowatt =	1,000 watts. 1.34 horse-power. 2,654,200 ft.-lbs. per hour. 44,240 ft.-lbs. per minute. 737.3 ft.-lbs. per second. 3,412 heat-units per hour. 56.9 heat-units per minute. 0.948 heat-unit per second. 0.2275 lb. carbon oxidized per hour. 3.53 lbs. water evaporated per hour from and at 212° F.

Mechanical, Electrical and Heat Equivalents (Continued)

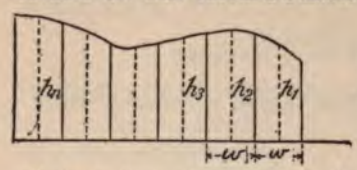
Unit.	Equivalent Value in Other Units.
1 H. P. =	746 watts. 0.746 K. W. 33,000 ft.-lbs. per minute. 550 ft.-lbs. per second. 2,545 heat-units per hour. 42.4 heat-units per minute. 0.707 heat units per second. 0.175 lbs. carbon oxidized per hour. 2.64 lbs. water evaporated per hour from and at 212° F.
1 Joule =	1 watt second. 0.000000278 K. W. hour. 0.102 k. g. m. 0.0009477 heat-units. 0.7373 ft.-lb.
1 Ft.-lb. =	1.356 joules. 0.1383 k. g. m. 0.000000377 K. W. hours. 0.001285 heat-units. 0.0000005 H. P. hour.
1 Watt =	1 joule per second. 0.00134 H. P. 3.412 heat-units per hour. 0.7373 ft.-lb. per second. 0.0035 lb. water evaporated per hour. 44.24 ft.-lbs. per minute.
1 Watt per sq. in. =	8.19 heat-units per square foot per minute. 6371 ft.-lbs. per square foot per minute. 0.193 H. P. per square foot.

Mensuration and Mathematical Tables

Mensuration of Surfaces.

Area of any parallelogram	= base × perpendicular height.
" " " triangle	= base × ½ perpendicular height.
" " " circle	= (diameter)^2 × (0.7854, or approx. 11/14.)
" " sector of circle....	= arc × 1/2 radius.
" " segment of circle .	= area of sector of equal radius and arc less area of triangle.
" " parabola.....	= base × 2/3 height.
" " ellipse.....	= longest diameter × shortest diameter × 0.7854.
" " cycloid.....	= area of generating circle × 3.
" " any regular polygon	= sum of its sides × perpendicular from its center to one of its sides ÷ 2.
Surface of cylinder.....	= area of both ends + (length × circumference.)
" " cone.....	= area of base + (circumference of base × ½ slant height.)
" " sphere..... ...	= (diameter)^2 × (3.1416, or approx. 22/7.)
" " frustum.....	= (sum of girt at both ends × ½ slant height) + area of both ends.
Surface of cylindrical ring	= thickness of ring added to the inner diameter × by the thickness × 9.8698.
Surface of segment	= height of segment × by whole circumference of sphere of which it is a part.

AREA OF AN IRREGULAR PLANE SURFACE



Divide the surface into any number of parallel strips of equal widths, "w." Take the sum of the middle ordinates h_1, h_2, etc., to h_n, inclusive; then the sum of these middle ordinates, multiplied by "w," will give the area required.

The result, of course, is only approximate, the closeness of the approximation depending upon the number of strips into which the surface is divided.

Any degree of accuracy desired may be attained by making the number of strips sufficiently numerous. In practice it is usually best to determine the area of an irregular figure by the use of a planimeter, an instrument especially designed for measuring areas of plain figures.

REGULAR POLYGONS

1. To find the area of any regular polygon, square one of its sides, and multiply this square by the corresponding number in the third column of the following table.

TABLE OF REGULAR POLYGONS

No. of Sides.	Name of Polygon.	Area = $S^2 \times$	Radius = $S \times$	Side = $R \times$	Angle contained between two sides.
3	Equilateral triangle	.433	.5774	1.732	60°
4	Square	1.	.7071	1.4142	90°
5	Pentagon	1.7205	.8507	1.1756	108°
6	Hexagon	2.5891	1.	1.	120°
7	Heptagon	3.6339	1.1524	.8678	128.57°
8	Octagon	4.8284	1.3066	.7654	135°
9	Nonagon	6.1818	1.4619	.684	140°
10	Decagon	7.6942	1.618	.618	144°
11	Undecagon	9.3656	1.7747	.5635	147.27°
12	Dodecagon	11.1962	1.9319	.5176	150°

2. Having a side of a regular polygon, to find the radius of a circumscribing circle. Multiply the side by the corresponding number in the fourth column.

3. Having the radius of a circumscribing circle, to find the side of the inscribed regular polygon. Multiply the radius by the corresponding number in the fifth column.

In the above table S = side of polygon and R = radius of circumscribing circle.

PROPERTIES OF THE CIRCLE

Diameter	$\times$ 3.1416	= circumference.
Diameter	$\times$ 0.8862	= side of an equivalent sq.
Diameter	$\times$ 0.7071	= side of an inscribed square.
$(\text{Diameter})^2$	$\times$ 0.7854	= area of circle.
Radius	$\times$ 6.2832	= circumference.
Circumference	$\div$ 3.1416	= diameter.

The circle contains a greater area than any plane figure, bounded by an equal perimeter, or outline.

The areas of circles are to each other as the squares of their diameter, radii or circumferences. Thus, a circle whose diameter is double that of another has four times the area of the other.

Volumes of Solids

Vol. of Cylinder	= area of one end × length.
" " Sphere.....	= cube of diameter × 0.5236.
" " Segment of sphere .	= (cube of the height + three times the square of radius of base × height) × 0.5236.
" " Cone or pyramid...	= area of base × ⅓ perpendicular height.
" " Frustum of cone...	= (product of diameter of both ends + sum of their squares) × perpendicular height × 0.2618.
" " Frustum of pyramid	= (sum of the areas of the two ends + square root of their product) × by ⅓ of the perpendicular height.
" " Wedge.....	= area of base × ½ perpendicular height.
" " Frustum of wedge..	= ½ perpendicular height × sum of the areas of the two ends.
" " Ring	= (thickness + inner diameter) × square of the thickness × 2.4674.

Water at Different Temperatures

There are four notable temperatures for pure water, viz.:

1. Freezing point at sea level.....32° F.
2. Point of maximum density.....39.1° F.
3. British standard for specific gravity....62° F.
4. Boiling point at sea level.....212° F.

A United States Standard gallon holds 231 cubic inches and 8⅓ lbs. of water at 62° F.

A British Imperial gallon holds 277.274 cubic inches and 10 lbs. of water at 62° F.

Sea water (average) has a specific gravity of 1.028, boils at 213.2° F., and weighs 64 lbs. per cubic foot at 62° F.

A pressure of 1 lb. per sq. in. is exerted by a column of water 2.3093 ft., or 27.71 in. high, at 62° F.

Relative Value of Non-Conductors

	Value.
Wood felts	1.000
Mineral wool, No. 2	0.832
Mineral wool, with tar	0.715
Sawdust	0.680
Mineral wool, No. 1	0.676
Charcoal	0.632
Pine wood, across fibre	0.553
Loam, dry and open	0.550
Slacked lime	0.480
Gas-house carbon	0.470
Asbestos	0.363
Coal ashes	0.345
Coke, in lumps	0.277
Air space, undivided	0.186

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
1/64	.04909	.00019	2.1/8	6.6759	3.5466	5.7/16	17.082	23.221
1/32	.09818	.00077	1/8	6.8722	3.7583	1/2	17 279	23.758
3/64	.14726	.00173	1/4	7.0686	3.9761	9/16	17.475	24.301
1/16	.19635	.00307	3/8	7.2649	4.2000	5/8	17.671	24.850
5/64	.29452	.00690	1/2	7.4613	4.4301	11/16	17.868	25.406
3/32	.39270	.01227	5/8	7.6576	4.6664	3/4	18.064	25.967
7/64	.49087	.01917	3/4	7.8540	4.9087	13/16	18.261	26.535
1/8	.58905	.02761	7/8	8.0503	5.1572	7/8	18.457	27.109
9/64	.68722	.03758	3.0	8.2467	5.4119	15/16	18.653	27.688
			1/8	8.4430	5.6727			
1/4	.78540	.04909	1/4	8.6394	5.9396	6.	18.850	28.274
5/64	.88357	.06213	3/8	8.8357	6.2126	1/16	19.242	29.465
11/64	.98175	.07670	1/2	9.0321	6.4918	1/8	19.635	30.680
3/16	1.0799	.09281	5/8	9.2284	6.7771	3/16	20.028	31.919
13/64	1.1781	.11045				1/4	20.420	33.183
7/32	1.2763	.12962	3.	9.4248	7.0686	5/16	20.813	34.472
15/64	1.3744	.15033	1/8	9.6211	7.3662	3/8	21.206	35.785
1/4	1.4726	.17257	1/4	9.8175	7.6699	7/16	21.598	37.122
			3/8	10.014	7.9798			
1/4	1.5708	.19635	1/2	10.210	8.2958	7.	21.991	38.485
17/64	1.6690	.22166	5/8	10.407	8.6179	1/16	22.384	39.871
9/32	1.7671	.24850	3/4	10.603	8.9462	1/8	22.776	41.282
19/64	1.8653	.27688	7/8	10.799	9.2806	3/16	23.169	42.718
5/16	1.9635	.30680	4.	10.996	9.6211	1/4	23.562	44.179
21/64	2.0617	.33824	1/8	11.192	9.9678	5/16	23.955	45.664
11/32	2.1598	.37122	1/4	11.388	10.321	3/8	24.347	47.173
23/64	2.2580	.40574	3/8	11.585	10.680	7/16	24.740	48.707
			1/2	11.781	11.045			
3/8	2.3562	.44179	5/8	11.977	11.416	8.	25.133	50.265
25/64	2.4544	.47937	3/4	12.174	11.793	1/16	25.525	51.849
13/32	2.5525	.51849	7/8	12.370	12.177	1/8	25.918	53.456
27/64	2.6507	.55914				3/16	26.311	55.088
7/16	2.7489	.60132	4.	12.566	12.566	1/4	26.704	56.745
29/64	2.8471	.64504	1/8	12.763	12.962	5/16	27.096	58.426
15/32	2.9452	.69029	1/4	12.959	13.364	3/8	27.489	60.132
31/64	3.0434	.73708	3/8	13.155	13.772	7/16	27.882	61.862
			1/2	13.352	14.186			
1.	3.1416	.7854	5/8	13.548	14.607	9.	28.274	63.617
1/32	3.3379	.8866	3/4	13.744	15.033	1/16	28.667	65.397
1/16	3.5343	.9940	7/8	13.941	15.466	1/8	29.060	67.201
3/32	3.7306	1.1075	5.	14.137	15.904	3/16	29.452	69.029
1/8	3.9270	1.2272	1/8	14.334	16.349	1/4	29.845	70.882
5/32	4.1233	1.3530	1/4	14.530	16.800	5/16	30.238	72.760
3/16	4.3197	1.4849	3/8	14.726	17.257	3/8	30.631	74.662
7/32	4.5160	1.6230	1/2	14.923	17.728	7/16	31.023	76.589
1/4	4.7124	1.7671	5/8	15.119	18.190			
9/32	4.9087	1.9175	3/4	15.315	18.665	10.	31.416	78.540
5/16	5.1051	2.0739	7/8	15.512	19.147	1/16	31.809	80.516
11/32	5.3014	2.2365				1/8	32.201	82.516
3/8	5.4978	2.4053	5.	15.708	19.635	3/16	32.594	84.541
13/32	5.6941	2.5802	1/8	15.904	20.129	1/4	32.987	86.590
7/16	5 8905	2.7612	1/4	16.101	20.629	5/16	33.379	88.664
15/32	6.0868	2.9483	3/8	16.297	21.135	3/8	33.772	90.763
			1/2	16.493	21.648	7/16	34.165	92.886
2.	6.2832	3.1416	5/8	16.690	22.166			
1/16	6.4795	3.3410	3/4	16.886	22.691	11.	34.558	95.033

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
11.	34.550	97.205	17.	53.585	237.10	23.	72.220	438.36
1/16	34.943	99.402	1/16	53.978	240.53	1/16	72.613	443.01
1/8	35.736	101.62	1/8	54.371	243.98	1/8	73.006	447.69
3/16	35.128	103.87	3/16	54.763	247.45	3/16		
1/4	35.521	106.14	1/4	55.156	250.95	1/4	73.398	452.39
5/16	35.914	108.43	5/16			5/16	73.791	457.11
3/8	37.306	110.75	3/8	55.549	254.47	3/8	74.184	461.86
12.	37.699	113.10	18.	55.941	258.02	24.	74.576	466.64
1/16	38.092	115.47	1/16	56.334	261.59	1/16	74.969	471.44
1/8	38.485	117.86	1/8	56.727	265.18	1/8	75.362	476.26
3/16	38.877	120.28	3/16	57.119	268.80	3/16	75.754	481.11
1/4	39.270	122.72	1/4	57.512	272.45	1/4	76.147	485.98
5/16	39.663	125.19	5/16	57.905	276.12	5/16		
3/8	40.055	127.68	3/8	58.298	279.81	3/8	76.540	490.87
13.	40.448	130.19	19.	58.690	283.53	25.	76.933	495.79
1/16	40.841	132.73	1/16	59.083	287.27	1/16	77.325	500.74
1/8	41.233	135.30	1/8	59.476	291.04	1/8	77.718	505.71
3/16	41.626	137.89	3/16	59.868	294.83	3/16	78.111	510.71
1/4	42.019	140.50	1/4	60.261	298.65	1/4	78.503	515.72
5/16	42.412	143.14	5/16	60.654	302.49	5/16	78.896	520.77
3/8	42.804	145.80	3/8	61.046	306.35	3/8	79.289	525.84
14.	43.197	148.49	20.	61.439	310.24	26.	79.681	530.93
1/16	43.590	151.20	1/16	61.832	314.16	1/16	80.074	536.05
1/8	43.982	153.94	1/8	62.225	318.10	1/8	80.467	541.19
3/16	44.375	156.70	3/16	62.617	322.06	3/16	80.860	546.35
1/4	44.768	159.48	1/4	63.010	326.05	1/4	81.252	551.55
5/16	45.160	162.30	5/16	63.403	330.06	5/16	81.645	556.76
3/8	45.553	165.13	3/8	63.795	334.10	3/8	82.038	562.00
15.	45.946	167.99	21.	64.188	338.16	27.	82.430	567.27
1/16	46.338	170.87	1/16	64.581	342.25	1/16	82.823	572.56
1/8	46.731	173.78	1/8	64.973	346.36	1/8	83.216	577.87
3/16	47.124	176.71	3/16	65.366	350.50	3/16	83.608	583.21
1/4	47.517	179.67	1/4	65.759	354.66	1/4	84.001	588.57
5/16	47.909	182.65	5/16	66.152	358.84	5/16	84.394	593.96
3/8	48.302	185.66	3/8	66.544	363.05	3/8	84.786	599.37
16.	48.695	188.69	22.	66.937	367.28	28.	85.179	604.81
1/16	49.087	191.75	1/16	67.330	371.54	1/16	85.572	610.27
1/8	49.480	194.83	1/8	67.722	375.83	1/8	85.965	615.75
3/16	49.873	197.93	3/16	68.115	380.13	3/16	86.357	621.26
1/4	50.265	201.06	1/4	68.508	384.46	1/4	86.750	626.80
5/16	50.658	204.22	5/16	68.900	388.82	5/16	87.143	632.36
3/8	51.051	207.39	3/8	69.293	393.20	3/8	87.535	637.94
17.	51.444	210.60	23.	69.686	397.61	29.	87.928	643.55
1/16	51.836	213.82	1/16	70.079	402.04	1/16	88.321	649.18
1/8	52.229	217.08	1/8	70.471	406.49	1/8	88.713	654.84
3/16	52.622	220.35	3/16	70.864	410.97	3/16	89.106	660.52
1/4	53.014	223.65	1/4	71.257	415.48	1/4	89.499	666.23
5/16	53.407	226.98	5/16	71.649	420.00	5/16	89.891	671.96
3/8	53.800	230.33	3/8	72.042	424.56	3/8	90.284	677.71
18.	54.192	233.71	24.	72.435	429.13	30.	90.677	683.49
1/16			1/16	72.827	433.74	1/16	91.070	689.30
1/8			1/8			1/8	91.462	695.13

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
29. 3/8	93.855	700.98	36. 1/8	113.490	1025.0	42. 3/8	133.125	1410.3
			1/4	113.883	1032.1	1/2	133.518	1418.6
30.	94.248	706.86	3/8	114.275	1039.2	5/8	133.910	1427.0
1/8	94.640	712.76	1/2	114.668	1046.3	3/4	134.303	1435.4
1/4	95.033	718.69	5/8	115.061	1053.5	7/8	134.696	1443.8
3/8	95.426	724.64	3/4	115.454	1060.7			
1/2	95.819	730.62	7/8	115.846	1068.0	43.	135.088	1452.2
5/8	96.211	736.62				1/8	135.481	1460.7
3/4	96.604	742.64	37.	116.239	1075.2	1/4	135.874	1469.1
7/8	96.997	748.69	1/8	116.633	1082.5	3/8	136.267	1477.6
			1/4	117.024	1089.8	1/2	136.659	1486 2
31.	97.389	754.77	3/8	117.417	1097.1	5/8	137.052	1494.7
1/8	97.782	760.87	1/2	117.810	1104.5	3/4	137.445	1503.3
1/4	98.175	766.99	5/8	118.202	1111.8	7/8	137.837	1511.9
3/8	98.567	773.14	3/4	118.596	1119.2			
1/2	98.960	779.31	7/8	118.968	1126.7	44.	138.230	1520.5
5/8	99.353	785.51				1/8	138.623	1529.2
3/4	99.746	791.73	38.	119.381	1134.1	1/4	139.015	1537.9
7/8	100.138	797.98	1/8	119.773	1141.6	3/8	139.408	1546.6
			1/4	120.166	1149.1	1/2	139.801	1555.3
32.	100.531	804.25	3/8	120.559	1156.6	5/8	140.194	1564.0
1/8	100.924	810.54	1/2	120.951	1164.2	3/4	140.586	1572.8
1/4	101.316	816.86	5/8	121.344	1171.7	7/8	140.979	1581 6
3/8	101.709	823.21	3/4	121.737	1179.3			
1/2	102.102	829.58	7/8	122.129	1186.9	45.	141.372	1590.4
5/8	102.494	835.97				1/8	141.764	1599.3
3/4	102.887	842.39	39.	122.522	1194.6	1/4	142.157	1608.2
7/8	103.280	848.83	1/8	122.915	1202.3	3/8	142.550	1617.0
			1/4	123.308	1210.0	1/2	142.942	1626.0
33.	103.673	855.30	3/8	123.700	1217.7	5/8	143.335	1634.9
1/8	104.065	861.79	1/2	124.093	1225.4	3/4	143.728	1643.9
1/4	104.458	868.31	5/8	124.486	1233.2	7/8	144.121	1652.9
3/8	104.851	874.85	3/4	124.878	1241.0			
1/2	105.243	881.41	7/8	125.271	1248.8	46.	144.513	1661.9
5/8	105.636	888.00				1/8	144.906	1670.9
3/4	106.029	894.62	40.	125.664	1256.6	1/4	145.299	1680.0
7/8	106.421	901.26	1/8	126.056	1264.5	3/8	145.691	1689.1
			1/4	126.449	1272.4	1/2	146.084	1698.2
34.	106.814	907.92	3/8	126.842	1280.3	5/8	146.477	1707.4
1/8	107.207	914.61	1/2	127.235	1288.2	3/4	146.869	1716.5
1/4	107.600	921.32	5/8	127.627	1296.2	7/8	147.262	1725.7
3/8	107.992	928.06	3/4	128.020	1304.2			
1/2	108.385	934.82	7/8	128.413	1312.2	47.	147.655	1734.9
5/8	108.778	941.61				1/8	148.048	1744.2
3/4	109.170	948.42	41.	128.805	1320.3	1/4	148.440	1753.5
7/8	109.563	955.25	1/8	129.198	1328.3	3/8	148.833	1762.7
			1/4	129.591	1336.4	1/2	149.226	1772.1
35.	109.956	962.11	3/8	129.983	1344.5	5/8	149.618	1781.4
1/8	110.348	969.00	1/2	130.376	1352.7	3/4	150.011	1790.8
1/4	110.741	975.91	5/8	130.769	1360.8	7/8	150.404	1800.1
3/8	111.134	982.84	3/4	131.161	1369.0			
1/2	111.527	989.80	7/8	131.554	1377.2	48.	150.796	1809.6
5/8	111.919	996.78				1/8	151.189	1819.0
3/4	112.312	1003.8	42.	131.947	1385.4	1/4	151.582	1828.5
7/8	112.705	1010.8	1/8	132.340	1393.7	3/8	151.975	1837.9
36.	113.097	1017.9	1/4	132.732	1402.0	1/2	152.367	1847.5

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
48.	150.796	1809.6	54.	169.646	2290.2	60.	188.496	2827.4
1/8	151.188	1819.4	1/8	170.039	2300.8	1/8	188.888	2839.2
1/4	151.580	1829.2	1/4	170.431	2311.5	1/4	189.281	2851.0
3/8	151.972	1839.0	3/8	170.824	2322.1	3/8	189.674	2862.9
1/2	152.365	1848.8	1/2	171.217	2332.8	1/2	190.066	2874.8
5/8	152.757	1858.7	5/8	171.609	2343.5	5/8	190.459	2886.6
3/4	153.149	1868.5	3/4	172.002	2354.3	3/4	190.852	2898.6
7/8	153.545	1876.1	7/8	172.395	2365.0	7/8	191.244	2910.5
49.	153.938	1885.7	55.	172.788	2375.8	61.	191.637	2922.5
1/8	154.331	1895.4	1/8	173.180	2386.6	1/8	192.030	2934.5
1/4	154.723	1905.0	1/4	173.573	2397.5	1/4	192.423	2946.5
3/8	155.116	1914.7	3/8	173.966	2408.3	3/8	192.815	2958.5
1/2	155.509	1924.4	1/2	174.358	2419.2	1/2	193.208	2970.6
5/8	155.902	1934.2	5/8	174.751	2430.1	5/8	193.601	2982.7
3/4	156.294	1943.9	3/4	175.144	2441.1	3/4	193.993	2994.8
7/8	156.687	1953.7	7/8	175.536	2452.0	7/8	194.386	3006.9
50.	157.080	1963.5	56.	175.929	2463.0	62.	194.779	3019.1
1/8	157.472	1973.3	1/8	176.322	2474.0	1/8	195.171	3031.3
1/4	157.865	1983.2	1/4	176.715	2485.0	1/4	195.564	3043.5
3/8	158.258	1993.1	3/8	177.107	2496.1	3/8	195.957	3055.7
1/2	158.650	2003.0	1/2	177.500	2507.2	1/2	196.350	3068.0
5/8	159.043	2012.9	5/8	177.893	2518.3	5/8	196.742	3080.3
3/4	159.436	2022.8	3/4	178.285	2529.4	3/4	197.135	3092.6
7/8	159.829	2032.8	7/8	178.678	2540.6	7/8	197.528	3104.9
51.	160.221	2042.8	57.	179.071	2551.8	63.	197.920	3117.2
1/8	160.614	2052.8	1/8	179.463	2563.0	1/8	198.313	3129.6
1/4	161.007	2062.9	1/4	179.856	2574.2	1/4	198.706	3142.0
3/8	161.399	2073.0	3/8	180.249	2585.4	3/8	199.098	3154.5
1/2	161.792	2083.1	1/2	180.642	2596.7	1/2	199.491	3166.9
5/8	162.185	2093.2	5/8	181.034	2608.0	5/8	199.884	3179.4
3/4	162.577	2103.3	3/4	181.427	2619.4	3/4	200.277	3191.9
7/8	162.970	2113.5	7/8	181.820	2630.7	7/8	200.669	3204.4
52.	163.363	2123.7	58.	182.212	2642.1	64.	201.062	3217.0
1/8	163.756	2133.9	1/8	182.605	2653.5	1/8	201.455	3229.6
1/4	164.148	2144.2	1/4	182.998	2664.9	1/4	201.847	3242.2
3/8	164.541	2154.5	3/8	183.390	2676.4	3/8	202.240	3254.8
1/2	164.934	2164.8	1/2	183.783	2687.8	1/2	202.633	3267.5
5/8	165.326	2175.1	5/8	184.176	2699.3	5/8	203.025	3280.1
3/4	165.719	2185.4	3/4	184.569	2710.9	3/4	203.418	3292.8
7/8	166.112	2195.8	7/8	184.961	2722.4	7/8	203.811	3305.6
53.	166.504	2206.2	59.	185.354	2734.0	65.	204.204	3318.3
1/8	166.897	2216.6	1/8	185.747	2745.6	1/8	204.596	3331.1
1/4	167.290	2227.0	1/4	186.139	2757.2	1/4	204.989	3343.9
3/8	167.683	2237.5	3/8	186.532	2768.8	3/8	205.382	3356.7
1/2	168.075	2248.0	1/2	186.925	2780.5	1/2	205.774	3369.6
5/8	168.468	2258.5	5/8	187.317	2792.2	5/8	206.167	3382.4
3/4	168.861	2269.1	3/4	187.710	2803.9	3/4	206.560	3395.3
7/8	169.253	2279.6	7/8	188.103	2815.7	7/8	206 952	3408.2
						66.	207.345	3421.2
						1/8	207.738	3434.2
						1/4	208.131	3447.2
						3/8	208.523	3460.2
						1/2	208.916	3473.2
						5/8	209.309	3486.3
						3/4	209.701	3499.4
						7/8	210.094	3512.5
						67.	210.487	3525.7
						1/8	210.879	3538.8

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
67.	211.272	3552.0	73.	230.907	4242.9	79.	250.542	4995.2
1/8	211.665	3565.2	1/8	231.300	4257.4	1/8	250.935	5010.9
1/4	212.058	3578.5	1/4	231.692	4271.8			
3/8	212.450	3591.7	3/8	232.085	4286.3	80.	251.327	5026.5
1/2	212.843	3605.0				1/8	251.720	5042.3
5/8	213.236	3618.3	74.	232.478	4300.8	1/4	252.113	5058.0
3/4			1/8	232.871	4315.4	3/8	252.506	5073.8
7/8			1/4	233.263	4329.9	1/2	252.898	5089.6
68.	213.628	3631.7	3/8	233.656	4344.5	5/8	253.291	5105.4
1/8	214.021	3645.0	1/2	234.049	4359.2	3/4	253.684	5121.2
1/4	214.414	3658.4	5/8	234.441	4373.8	7/8	254.076	5137.1
3/8	214.806	3671.8	3/4	234.834	4388.5			
1/2	215.199	3685.3	7/8	235.227	4403.1	81.	254.469	5153.0
5/8	215.592	3698.7				1/8	254.862	5168.9
3/4	215.984	3712.2	75.	235.619	4417.9	1/4	255.254	5184.9
7/8	216.377	3725.7	1/8	236.012	4432.6	3/8	255.647	5200.8
69.	216.770	3739.3	1/4	236.405	4447.4	1/2	256.040	5216.8
1/8	217.163	3752.8	3/8	236.798	4462.2	5/8	256.433	5232.8
1/4	217.555	3766.4	1/2	237.190	4477.0	3/4	256.825	5248.9
3/8	217.948	3780.0	5/8	237.583	4491.8	7/8	257.218	5264.9
1/2	218.341	3793.7	3/4	237.976	4506.7			
5/8	218.733	3807.3	7/8	238.368	4521.5	82.	257.611	5281.0
3/4	219.126	3821.0				1/8	258.003	5297.1
7/8	219.519	3834.7	76.	238.761	4536.5	1/4	258.396	5313.3
70.	219.911	3848.5	1/8	239.154	4551.4	3/8	258.789	5329.4
1/8	220.304	3862.2	1/4	239.546	4566.4	1/2	259.181	5345.6
1/4	220.697	3876.0	3/8	239.939	4581.3	5/8	259.574	5361.8
3/8	221.090	3889.8	1/2	240.332	4596.3	3/4	259.967	5378.1
1/2	221.482	3903.6	5/8	240.725	4611.4	7/8	260.359	5394.3
5/8	221.875	3917.5	3/4	241.117	4626.4			
3/4	222.268	3931.4	7/8	241.510	4641.5	83.	260.752	5410.6
7/8	222.660	3945.3				1/8	261.145	5426.9
			77.	241.903	4656.6	1/4	261.538	5443.3
71.	223.053	3959.2	1/8	242.295	4671.8	3/8	261.930	5459.6
1/8	223.446	3973.1	1/4	242.688	4686.9	1/2	262.323	5476.0
1/4	223.838	3987.1	3/8	243.081	4702.1	5/8	262.716	5492.4
3/8	224.231	4001.1	1/2	243.473	4717.3	3/4	263.108	5508.8
1/2	224.624	4015.2	5/8	243.866	4732.5	7/8	263.501	5525.3
5/8	225.017	4029.2	3/4	244.259	4747.8			
3/4	225.409	4043.3	7/8	244.652	4763.1	84.	263.894	5541.8
7/8	225.802	4057.4				1/8	264.286	5558.3
			78.	245.044	4778.4	1/4	264.679	5574.8
72.	226.195	4071.5	1/8	245.437	4793.7	3/8	265.072	5591.4
1/8	226.587	4085.7	1/4	245.830	4809.0	1/2	265.465	5607.9
1/4	226.980	4099.8	3/8	246.222	4824.4	5/8	265.857	5624.5
3/8	227.373	4114.0	1/2	246.615	4839.8	3/4	266.250	5641.2
1/2	227.765	4128.2	5/8	247.008	4855.2	7/8	266.643	5657.8
5/8	228.158	4142.5	3/4	247.400	4870.7			
3/4	228.551	4156.8	7/8	247.793	4886.2	85.	267.035	5674.5
7/8	228.944	4171.1				1/8	267.428	5691.2
			79.	248.186	4901.7	1/4	267.821	5707.9
73.	229.336	4185.4	1/8	248.579	4917.2	3/8	268.213	5724.7
1/8	229.729	4199.7	1/4	248.971	4932.7	1/2	268.606	5741.5
1/4	230.122	4214.1	3/8	249.364	4948.3	5/8	268.999	5758.3
3/8	230.514	4228.5	1/2	249.757	4963.9	3/4	269.392	5775.1
			5/8	250.149	4979.5	7/8	269.784	5791.9

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
86.	270.177	5808.8	90. 7/8	285.492	6486.0	95. 5/8	300.415	7181.8
1/8	270.570	5825.7				3/4	300.807	7200.6
1/4	270.962	5842.6	91.	285.885	6503.9	7/8	301.200	7219.4
3/8	271.355	5859.6	1/8	286.278	6521.8			
1/2	271.748	5876.5	1/4	286.670	6539.7	96.	301.593	7238.2
5/8	272.140	5893.5	3/8	287.063	6557.6	1/8	301.986	7257.1
3/4	272.533	5910.6	1/2	287.456	6575.5	1/4	302.378	7276.0
7/8	272.926	5927.6	5/8	287.848	6593.5	3/8	302.771	7294.9
			3/4	288.241	6611.5	1/2	303.164	7313.8
87.	273.319	5944.7	7/8	288.634	6629.6	5/8	303.556	7332.8
1/8	273.711	5961.8				3/4	303.949	7351.8
1/4	274.104	5978.9	92.	289.027	6647.6	7/8	304.342	7370.8
3/8	274.497	5996.0	1/8	289.419	6665.7			
1/2	274.889	6013.2	1/4	289.812	6683.8	97.	304.734	7389.8
5/8	275.282	6030.4	3/8	290.205	6701.9	1/8	305.127	7408.9
3/4	275.675	6047.6	1/2	290.597	6720.1	1/4	305.520	7428.0
7/8	276.067	6064.9	5/8	290.990	6738.2	3/8	305.913	7447.1
			3/4	291.383	6756.4	1/2	306.305	7466.2
88.	276.460	6082.1	7/8	291.775	6774.7	5/8	306.698	7485.3
1/8	276 853	6099.4				3/4	307.091	7504.5
1/4	277.246	6116.7	93.	292.168	6792.9	7/8	307.483	7523.7
3/8	277.638	6134.1	1/8	292.561	6811.2			
1/2	278.031	6151.4	1/4	292.954	6829.5	98.	307.876	7543.0
5/8	278.424	6168.8	3/8	293.346	6847.8	1/8	308.269	7562.2
3/4	278.816	6186.2	1/2	293.739	6866.1	1/4	308.661	7581.5
7/8	279.209	6203.7	5/8	294.132	6884.5	3/8	309.054	7600.8
			3/4	294.524	6902.9	1/2	309.447	7620.1
89.	279.602	6221.1	7/8	294.917	6921 3	5/8	309.840	7639.5
1/8	279.994	6238.6				3/4	310.232	7658.9
1/4	280.387	6256.1	94.	295.310	6939.8	7/8	310.625	7678.3
3/8	280.780	6273.7	1/8	295.702	6958.2			
1/2	281.173	6291.2	1/4	296.095	6976.7	99.	311.018	7697.7
5/8	281.565	6308.8	3/8	296.488	6995.3	1/8	311.410	7717.1
3/4	281.958	6326 4	1/2	296.881	7013.8	1/4	311.803	7736.6
7/8	282.351	6344.1	5/8	297.273	7032.4	3/8	312.196	7756.1
			3/4	297.666	7051.0	1/2	312.588	7775.6
90.	282.743	6361.7	7/8	298.059	7069.6	5/8	312.981	7795.2
1/8	283.136	6379.4				3/4	313.374	7814.8
1/4	283.529	6397.1	95.	298.451	7088.2	7/8	313.767	7834.4
3/8	283.921	6414.9	1/8	298.844	7106.9			
1/2	284.314	6432.6	1/4	299.237	7125.6	100.	314.159	7854.0
5/8	284.707	6450.4	3/8	299.629	7144.3			
3/4	285.100	6468.2	1/2	300.022	7163.0			

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
67.	211.272	3552.0	73.	230.907	4242.9	79.	250.542	4995.2
1/8	211.665	3565.2	1/8	231.300	4257.4	3/4	250.935	5010.9
1/4	212.058	3578.5	1/4	231.692	4271.8	7/8		
3/8	212.450	3591.7	3/8	232.085	4286.3	80.	251.327	5026.5
1/2	212.843	3605.0	1/2			1/8	251.720	5042.3
3/4	213.236	3618.3	74.	233.478	4300.8	1/4	252.113	5058.0
7/8			1/8	232.871	4315.4	3/8	252.506	5073.8
68.	213.628	3631.7	1/4	233.263	4329.9	1/2	252.898	5089.6
1/8	214.021	3645.0	3/8	233.656	4344.5	5/8	253.291	5105.4
1/4	214.414	3658.4	1/2	234.049	4359.2	3/4	253.684	5121.2
3/8	214.806	3671.8	5/8	234.441	4373.8	7/8	254.076	5137.1
1/2	215.199	3685.3	3/4	234.834	4388.5			
5/8	215.592	3698.7	7/8	235.227	4403.1	81.	254.469	5153.0
3/4	215.984	3712.2				1/8	254.862	5168.9
7/8	216.377	3725.7	75.	235.619	4417.9	1/4	255.254	5184.9
69.	216.770	3739.3	1/8	236.012	4432.6	3/8	255.647	5200.8
1/8	217.163	3752.8	1/4	236.405	4447.4	1/2	256.040	5216.8
1/4	217.555	3766.4	3/8	236.798	4462.2	5/8	256.433	5232.8
3/8	217.948	3780.0	1/2	237.190	4477.0	3/4	256.825	5248.9
1/2	218.341	3793.7	5/8	237.583	4491.8	7/8	257.218	5264.9
5/8	218.733	3807.3	3/4	237.976	4506.7			
3/4	219.126	3821.0	7/8	238.368	4521.5	82.	257.611	5281.0
7/8	219.519	3834.7				1/8	258.003	5297.1
			76.	238.761	4536.5	1/4	258.396	5313.3
70.	219.911	3848.5	1/8	239.154	4551.4	3/8	258.789	5329.4
1/8	220.304	3862 2	1/4	239.546	4566.4	1/2	259.181	5345.6
1/4	220.697	3876.0	3/8	239.939	4581.3	5/8	259.574	5361.8
3/8	221.090	3889.8	1/2	240.332	4596.3	3/4	259.967	5378.1
1/2	221.482	3903.6	5/8	240.725	4611.4	7/8	260.359	5394 3
5/8	221.875	3917.5	3/4	241.117	4626.4			
3/4	222.268	3931.4	7/8	241.510	4641.5	83.	260.752	5410.6
7/8	222.660	3945.3				1/8	261.145	5426.9
			77.	241.903	4656.6	1/4	261.538	5443.3
71.	223.053	3959.2	1/8	242.295	4671.8	3/8	261.930	5459.6
1/8	223.446	3973.1	1/4	242.688	4686.9	1/2	262.323	5476.0
1/4	223.838	3987.1	3/8	243.081	4702.1	5/8	262.716	5492.4
3/8	224.231	4001.1	1/2	243.473	4717.3	3/4	263.108	5508.8
1/2	224.624	4015.2	5/8	243.866	4732.5	7/8	263.501	5525.3
5/8	225.017	4029.2	3/4	244.259	4747.8			
3/4	225.409	4043.8	7/8	244.652	4763.1	84.	263.894	5541.8
7/8	225.802	4057.4				1/8	264.286	5558.3
			78.	245.044	4778.4	1/4	264.679	5574.8
72.	226.195	4071.5	1/8	245.437	4793.7	3/8	265.072	5591.4
1/8	226.587	4085.7	1/4	245.830	4809.0	1/2	265.465	5607.9
1/4	226.980	4099.8	3/8	246.222	4824.4	5/8	265.857	5624.5
3/8	227.373	4114.0	1/2	246.615	4839.8	3/4	266.250	5641.2
1/2	227.765	4128.2	5/8	247.008	4855.2	7/8	266.643	5657.8
5/8	228.158	4142.5	3/4	247.400	4870.7			
3/4	228.551	4156.8	7/8	247.793	4886.2	85.	267.035	5674.5
7/8	228.944	4171.1				1/8	267.428	5691.2
			79.	248.186	4901.7	1/4	267.821	5707.9
73.	229.336	4185.4	1/8	248.579	4917.2	3/8	268.213	5724.7
1/8	229.729	4199.7	1/4	248.971	4932.7	1/2	268.606	5741.5
1/4	230.122	4214.1	3/8	249.364	4948.3	5/8	268.999	5758.3
3/8	230.514	4228.5	1/2	249.757	4963.9	3/4	269.392	5775.1
			5/8	250.149	4979.5	7/8	269.784	5791.9

Circumferences and Areas of Circles

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
86.	270.177	5808.8	90. 3/8	285.492	6486.0	95. 5/8	300.415	7181.8
1/8	270.570	5825.7				3/4	300.807	7200.6
1/4	270.962	5842.6	91.	285.885	6503.9	7/8	301.200	7219.4
3/8	271.355	5859.6	1/8	286.278	6521.8			
1/2	271.748	5876.5	1/4	286.670	6539.7	96.	301.593	7238.2
5/8	272.140	5893.5	3/8	287.063	6557.6	1/8	301.986	7257.1
3/4	272.533	5910.6	1/2	287.456	6575.5	1/4	302.378	7276.0
7/8	272.926	5927.6	5/8	287.848	6593.5	3/8	302.771	7294.9
			3/4	288.241	6611.5	1/2	303.164	7313.8
87.	273.319	5944.7	7/8	288.634	6629.6	5/8	303.556	7332.8
1/8	273.711	5961.8				3/4	303.949	7351.8
1/4	274.104	5978.9	92.	289.027	6647.6	7/8	304.342	7370.8
3/8	274.497	5996.0	1/8	289.419	6665.7			
1/2	274.889	6013.2	1/4	289.812	6683.8	97.	304.734	7389.8
5/8	275.282	6030.4	3/8	290.205	6701.9	1/8	305.127	7408.9
3/4	275.675	6047.6	1/2	290.597	6720.1	1/4	305.520	7428.0
7/8	276.067	6064.9	5/8	290.990	6738.2	3/8	305.913	7447.1
			3/4	291.383	6756.4	1/2	306.305	7466.2
88.	276.460	6082.1	7/8	291.775	6774.7	5/8	306.698	7485.3
1/8	276 853	6099.4				3/4	307.091	7504.5
1/4	277.246	6116.7	93.	292.168	6792.9	7/8	307.483	7523.7
3/8	277.638	6134.1	1/8	292.561	6811.2			
1/2	278.031	6151.4	1/4	292.954	6829.5	98.	307.876	7543.0
5/8	278.424	6168.8	3/8	293.346	6847.8	1/8	308.269	7562.2
3/4	278.816	6186.2	1/2	293.739	6866.1	1/4	308.661	7581.5
7/8	279.209	6203.7	5/8	294.132	6884.5	3/8	309.054	7600.8
			3/4	294.524	6902.9	1/2	309.447	7620.1
89.	279.602	6221.1	7/8	294.917	6921 3	5/8	309.840	7639.5
1/8	279.994	6238.6				3/4	310.232	7658.9
1/4	280.387	6256.1	94.	295.310	6939.8	7/8	310.625	7678.3
3/8	280.780	6273.7	1/8	295.702	6958.2			
1/2	281.173	6291.2	1/4	296.095	6976.7	99.	311.018	7697.7
5/8	281.565	6308.8	3/8	296.488	6995.3	1/8	311.410	7717.1
3/4	281.958	6326 4	1/2	296.881	7013.8	1/4	311.803	7736.6
7/8	282.351	6344.1	5/8	297.273	7032.4	3/8	312.196	7756.1
			3/4	297.666	7051.0	1/2	312.588	7775.6
90.	282.743	6361.7	7/8	298.059	7069.6	5/8	312.981	7795.2
1/8	283.136	6379.4				3/4	313.374	7814.8
1/4	283.529	6397.1	95.	298.451	7088.2	7/8	313.767	7834.4
3/8	283.921	6414.9	1/8	298.844	7106.9			
1/2	284.314	6432.6	1/4	299.237	7125.6	100.	314.159	7854.0
5/8	284.707	6450.4	3/8	299.629	7144.3			
3/4	285.100	6468.2	1/2	300.022	7163.0			
			5/8					

Fifth Roots and Fifth Powers

Power.	No. or Root.	Power.	No. or Root.	Power.	No. or Root.
.0000100	.1	.000796	.240	.034503	.51
.0000110	.102	.000883	.245	.038020	.52
.0000122	.104	.000977	.250	.041820	.53
.0000134	.106	.001078	.255	.045917	.54
.0000147	.108	.001188	.260	.050328	.55
.0000161	.110	.001307	.265	.055073	.56
.0000176	.112	.001435	.270	.060169	.57
.0000193	.114	.001573	.275	.065636	.58
.0000210	.116	.001721	.280	.071492	.59
0000229	.118	.001880	.285	.077760	.60
.0000249	.120	.002051	.290	.084460	.61
.0000270	.122	.002234	.295	.091613	.62
.0000293	.124	.002430	.300	.099244	.63
.0000318	.126	.002639	.305	.107374	.64
.0000344	.128	.002863	.310	.116029	.65
.0000371	.130	.003101	.315	.125233	.66
.0000401	.132	.003355	.320	.135013	.67
.0000432	.134	.003626	.325	.145393	.68
.0000465	.136	.003914	.330	.156403	.69
.0000500	.138	.004219	.335	.168070	.70
.0000538	.140	.004544	.340	.180423	.71
.0000577	.142	.004888	.345	.193492	.72
.0000619	.144	.005252	.350	.207307	.73
.0000663	.146	.005638	.355	.221901	.74
.0000710	.148	.006047	.360	.237305	.75
.0000754	.150	.006478	.365	.253553	.76
.0000895	.155	.006934	.370	.270678	.77
.000105	.160	.007416	.375	.288717	.78
.000122	.165	.007924	.380	.307706	.79
.000142	.170	.008459	.385	.327680	.80
.000164	.175	.009022	.390	.348678	.81
.000189	.180	.009616	.395	.370740	.82
.000217	.185	.010240	.400	.393904	.83
.000248	.190	.011586	.41	.418212	.84
.000282	.195	.013069	.42	.443705	.85
.000320	.200	.014701	.43	.470427	.86
.000362	.205	.016492	.44	.498421	.87
.000408	.210	.018453	.45	.527732	.88
.000459	.215	.020596	.46	.558406	.89
.000515	.220	.022935	.47	.590490	.90
.000577	.225	.025480	.48	.624032	.91
.000644	.230	.028248	.49	.659082	.92
.000717	.235	.031250	.50	.695688	.93

Fifth Roots and Fifth Powers

Power.	No. or Root.	Power.	No. or Root.	Power.	No. or Root.
.733904	.94	15.9495	1.74	525.319	3.50
.773781	.95	16.8874	1.76	563.822	3.55
.815373	.96	17.8690	1.78	604.662	3.60
.858734	.97	18.8957	1.80	647.835	3.65
.903921	.98	19.9690	1.82	693.440	3.70
.950990	.99	21.0906	1.84	741.577	3.75
1.	1.	22.2620	1.86	792.352	3.80
1.10408	1.02	23.4849	1.88	845.870	3.85
1.21665	1.04	24.7610	1.90	902.242	3.90
1.33823	1.06	26.0919	1.92	961.58	3.95
1.46933	1.08	27.4795	1.94	1024.00	4.00
1.61051	1.10	28.9255	1.96	1089.62	4.05
1.76234	1.12	30.4317	1.98	1158.56	4.10
1.92541	1.14	32.0000	2.00	1230.95	4.15
2.10034	1.16	36.2051	2.05	1306.91	4.20
2.28775	1.18	40.8410	2.10	1386.58	4.25
2.48832	1.20	45.9401	2.15	1470.08	4.30
2.70271	1.22	51.5363	2.20	1557.57	4.35
2.93163	1.24	57.6650	2.25	1649.16	4.40
3.17580	1.26	64.3634	2.30	1745.02	4.45
3.43597	1.28	71.6703	2.35	1845.28	4.50
3.71293	1.30	79.6262	2.40	1950.10	4.55
4.00746	1.32	88.2735	2.45	2059.63	4.60
4.32040	1.34	97.6562	2.50	2174.03	4.65
4.65259	1.36	107.820	2.55	2293.45	4.70
5.00490	1.38	118.814	2.60	2418.07	4.75
5.37824	1.40	130.686	2.65	2548.04	4.80
5.77353	1.42	143.489	2.70	2683.54	4.85
6.19174	1.44	157.276	2.75	2824.75	4.90
6.63383	1.46	172.104	2.80	2971.84	4.95
7.10082	1.48	188.029	2.85	3125.00	5.00
7.59375	1.50	205.111	2.90	3450.25	5.10
8.11368	1.52	223.414	2.95	3802.04	5.20
8.66171	1.54	243.000	3.00	4181.95	5.30
9.23896	1.56	263.936	3.05	4591.65	5.40
9.84658	1.58	286.292	3.10	5032.84	5.50
10.4858	1.60	310.136	3.15	5507.32	5.60
11.1577	1.62	335.544	3.20	6016.92	5.70
11.8637	1.64	362.591	3.25	6563.57	5.80
12.6049	1.66	391.354	3.30	7149.24	5.90
13.3828	1.68	421.419	3.35	7776.00	6.00
14.1986	1.70	454.354	3.40	8445.96	6.10
15.0537	1.72	488.760	3.45	9161.33	6.20

Fifth Roots and Fifth Powers

Power.	No. or Root.	Power.	No. or Root.	Power.	No. or Root.
9924.37	6.30	176234.	11.2	3043168.	19.8
10737.	6.40	192541.	11.4	3200000.	20.0
11603.	6.50	210034.	11.6	3363232.	20.2
12523.	6.60	228776.	11.8	3533059.	20.4
13501.	6.70	248832.	12.0	3709677.	20.6
14539.	6.80	270271.	12.2	3893289.	20.8
15640.	6.90	293163.	12.4	4084101.	21.0
16807.	7.00	317580.	12.6	4282322.	21.2
18042.	7.10	343597.	12.8	4488166.	21.4
19349.	7.20	371293.	13.0	4701850.	21.6
20731.	7.30	400746.	13.2	4923597.	21.8
22190.	7.40	432040.	13.4	5153632.	22.0
23730.	7.50	465259.	13.6	5392186.	22.2
25355.	7.60	500490.	13.8	5639493.	22.4
27068.	7.70	537824.	14.0	5895793.	22.6
28872.	7.80	577353.	14.2	6161327.	22.8
30771.	7.90	619174.	14.4	6436343.	23.0
32768.	8.00	663383.	14.6	6721093.	23.2
34868.	8.10	710082.	14.8	7015834.	23.4
37074.	8.20	759375.	15.0	7320825.	23.6
39390.	8.30	811368.	15.2	7636332.	23.8
41821.	8.40	866171.	15.4	7962624.	24.0
44371.	8.50	923896.	15.6	8299976.	24.2
47043.	8.60	984658.	15.8	8648666.	24.4
49842.	8.70	1048576.	16.0	9008978.	24.6
52773.	8.80	1115771.	16.2	9381200.	24.8
55841.	8.90	1186367.	16.4	9765625.	25.0
59049.	9.00	1260493.	16.6	10162550.	25.2
62403.	9.10	1338278.	16.8	10572278.	25.4
65908.	9.20	1419857.	17.0	10995116.	25.6
69569.	9.30	1505366.	17.2	11431377.	25.8
73390.	9.40	1594947.	17.4	11881376.	26.0
77378.	9.50	1688742.	17.6	12345437.	26.2
81537.	9.60	1786899.	17.8	12823886.	26.4
85873.	9.70	1889568.	18.0	13317055.	26.6
90392.	9.80	1996903.	18.2	13825281.	26.8
95099.	9.90	2109061.	18.4	14348907.	27.0
100000.	10.0	2226203.	18.6	14888280.	27.2
110408.	10.2	2348493.	18.8	15443752.	27.4
121665.	10.4	2476099.	19.0	16015681.	27.6
133823.	10.6	2609193.	19.2	16604430.	27.8
146933.	10.8	2747949.	19.4	17210368.	28.0
161051.	11.0	2892547.	19.6	17833868.	28.2

Fifth Roots and Fifth Powers

Power.	No. or Root.	Power.	No. or Root.	Power.	No. or Root.
18475809.	28.4	28629151.	31.0	60466176.	36.0
19135075.	28.6	31018643.	31.5	64783487.	36.5
19813557.	28.8	33554432.	32.0	69343957.	37.0
20511149.	29.0	36259082.	32.5	74157715.	37.5
21228253.	29.2	39135893.	33.0	79235168.	38.0
21965275.	29.4	42191410.	33.5	84587005.	38.5
22722628.	29.6	45435424.	34.0	90224199.	39.0
23500736.	29.8	48875980.	34.5	96158012.	39.5
24300000.	30.0	52521875.	35.0	102400000.	40.0
25090634.	30.5	56382167.	35.5		

Table of Altitudes and Boiling Points of Water

Locality	Elevation Above Sea Level, ft.	Boiling Point of Pure Water, deg. F.	Gauge Press. to give 212 deg. *F., lbs. and oz.	Temp. of Steam at 2 lbs. Gauge Press., deg. F.	Normal Barometric Pressure Inches of Mercury	Normal Atmos. Pressure per sq. in., lbs.
Atlanta, Ga.....	1,000	210.0	.. 9	216.9	28 88	14.18
Buffalo, N. Y....	600	210.8	.. 5	217.5	29.33	14.40
Butte, Mont....	5,700	201.1	2 14	209.1	24.14	11.86
Carson, Nev....	4,660	203.0	2 6	210.7	25 12	12.33
Chattanoga, Tenn.	674	210.6	.. 6	217.4	29.25	14.36
Cheyenne, Wyo...	6,000	200 5	3 .	208.6	23 86	11.72
Chicago, Ill.....	600	210.8	.. 5	217.5	29.33	14.40
Cincinnati, O.....	500	211.0	.. 4	217.7	29.44	14.46
Cleveland, O.....	642	210.7	.. 6	217.5	29 28	14.38
Col'rdo Spr'gs,Col.	5,982	200.5	3 ..	208.6	23 88	11.73
Dallas, Tex.....	425	211.1	.. 4	217 9	29.52	14 50
Denver, Col.....	5,279	201 9	2 11	209.7	24.53	12.04
Detroit, Mich....	600	210.8	.. 5	217.5	29.33	14.40
Helena, Mont ...	4,000	204.3	2 1	211.8	25.76	12.65
Knoxville, Tenn..	933	210.1	.. 8	217.0	28.95	14 22
Leadville, Col ..	10,190	192.9	4 12	201.9	20 34	9.98
Missoula, Mont...	3,200	205.8	1 10	213.1	26.55	13.03
Nashville, Tenn..	450	211 1	.. 4	217 8	29.50	14.48
Ogden, Utah	4,300	203.7	2 4	211.3	25.47	12.51
Pike's Peak, Col..	14,108	185.9	6 2	196.0	17.52	8.60
Provo, Utah.....	4,512	203 3	2 5	211.0	25.26	12.40
Pueblo, Col.....	4,660	203.0	2 6	210.7	25.12	12.33
Rochester, N. Y..	531	210.9	.. 5	217.7	29.41	14.44
St. Cloud, Minn..	1,020	210.0	.. 9	216.8	28 86	14.17
St. Louis, Mo....	450	211.1	4	217 8	29 50	14.48
St. Paul, Minn...	750	210.5	.. 7	217.3	29.16	14.32
Salt Lake City, Ut.	4,300	203.7	2 4	211.3	25 47	12.51
San Antonio, Tex	675	210.6	.. 6	217.4	29.24	14.36
Saranac Lake,N.Y.	1,574	208.9	.. 14	215.9	28.25	13.87
Spokane, Wash..	1,900	208.3	1 ..	215.3	27.90	13.70

* To give a temperature equal to 2 lbs. pressure at sea level (the basis on which boilers are rated) add 2 lbs. to the figures given in third column.

Weights of Various Materials

	Average Per Cu. Ft. Pounds
Aluminum	166
Antimony	419
Apple wood	48
Ash wood, white, dry	45
Asphaltum	87
Basalt	181
Beechwood	43
Birchwood	45
Boxwood	60
Bismuth	613
Brass, cast	524
Bronze	534
Brick, common	100 to 125
Brick, fire	150
Brick, chrome	175
Brick, magnesia	160
Cedar wood, West Indian	47
Cedar wood, American	35
Cedar wood, Lebanon	30
Cherry wood	42
Chestnut wood	41
Chrome ore dust, well shaken	160
Cork	15
Cement, Portland, loose	78
Cement, Rosendale	60
Chalk, solid	145
Charcoal, from birch	34
Charcoal, from fir	28
Charcoal, from oak	21
Charcoal, from pine	18
Clay, potters, dry	119
Clay, in lump, loose	63
Coal, anthracite	93.5
Coal, bituminous	84
Coal, cannel	79
Coke, loose	26.3
Concrete, in cement	137
Concrete, ordinary	119
Copper, cast	537
Copper wire	555
Earth, loam, dry, loose	76

Earth, loam, rammed	95
Earth, as soft-flowing mud	108
Earth, as dense mud	125
Ebony, dry	76
Elm, dry	35
Emery	250
Flint	162
Glass, flint	192
Glass, common window	157
Glass, plate	172
Glass, flooring	158
Gneiss, common	168
Gold, cast, 24 carat	1,204
Gold, pure, hammered	1,217
Grain, at 60 lbs. to the bushel	48
Granite, gray	163
Granite, red	165
Gravel	118
Gun-metal	528
Gun powder, coarse	57
Gun powder, fine	56
Gutta percha	60
Gypsum	143
Hemlock wood, dry	25
Hickory wood dry	53
Hornbeam wood, dry	47
Hornblende	203
Ice	58.7
Iron, cast	450
Iron, wrought, purest	485
Iron, wrought, average	480
Ironwood	71
Ivory	114
Larch wood	35
Lead, cast	708
Lead, rolled	711
Lignumvitæ wood, dry	83
Lime, quick, ground, loose or small lump	53
Lime, quick, ground, thoroughly shaken	75
Limestone	168
Limestone, irregular fragments	96
Magnesium	109
Magnesite, calcined	110
Mahogany wood, Spanish, dry	53
Mahogany wood, Honduras, dry	35
Maple wood, dry	49
Marble	168
Masonry, granite or limestone	165

Masonry, mortar rubble	154
Masonry, dry rubble	138
Masonry, sandstone, well dressed	144
Mercury, at 32 degrees Fahr	849
Mica	183
Millstone	155
Mortar, hardened	103
Oak, live, dry	59
Oak, white, dry	50
Petroleum	55
Pine, white, dry	25
Pine, Yellow, Northern	34
Pine, Yellow, Southern	45
Pitch	72
Plaster of Paris, cast	80
Platinum	1,342
Plumbago	140
Porphyry	170
Pumice stone	57
Quartz	165
Rosin	69
Salt, coarse, Syracuse, N. Y	45
Salt, fine, Liverpool	49
Sand, dry	100
Sand, well shaken	110
Sand, wet	130
Sandstone	151
Shales, red or black	162
Silver	655
Slate, American	175
Slate, Welsh	180
Spruce, dry	25
Steel	490
Sulphur	125
Sycamore, dry	37
Tallow	58.6
Tar	63
Tin, cast	459
Trap	170
Turf or Peat, dry, unpressed	25
Walnut wood	35
Wax, bee's	60.5
Water, at 32 degrees Fahr	62.418
Water, at 39.1 degrees Fahr	62.425
Water, at 62 degrees Fahr. (standard temp.)	62.355
Water, at 212 degrees Fahr	59.640
Zinc or spelter	437.5

Saturated Steam
Relative Pressure and Temperature
(Barometer 29.92 in.)

Absolute Pressure Lbs. Sq. In.	Vacuum Inches Mercury	Temperature Degrees Fahrenheit	Absolute Pressure Lbs. Sq. In.	Pressure Above Atmosphere Lbs. Sq. In.	Temp. Degrees Fahrenheit
.089	29.74	32.	24	9.3	237.8
.122	29.76	40.	25	10.3	240.0
.176	29.56	50.	26	11.3	242.2
.254	29.40	60.	27	12.3	244.3
.359	29.19	70.	28	13.3	246.3
.502	28.90	80.	29	14.3	248.3
.692	28.51	90.	30	15.3	250.2
.943	28.00	100.	31	16.3	252.1
1.	27.88	102.1	32	17.3	254.0
2.	25.85	126.3	33	18.3	255.7
3.	23.83	141.6	34	19.3	257.5
4.	21.78	153.1	35	20.3	259.2
5.	19.74	162.3	36	21.3	260.8
6.	17.70	170.1	37	22.3	262.5
7.	15.67	176.9	38	23.3	264.
8.	13.63	182.9	39	24.3	265.6
9.	11.60	188.3	40	25.3	267.1
10.	9.56	193.2	41	26.3	268.6
11.	7.52	197.8	42	27.3	270.1
12.	5.49	202.0	43	28.3	271.5
13.	3.45	205.9	44	29.3	272.9
14.	1.41	209.6	45	30.3	274.3
	Pressure above atmosphere lbs. sq. in.		46	31.3	275.7
			47	32.3	277.
			48	33.3	278.3
			49	34.3	279.6
			50	35.3	280.9
14.7	0.	212.	51	36.3	282.1
15.	0.304	213.	52	37.3	283.3
16.	1.3	216.3	53	38.3	284.5
17.	2.3	219.4	54	39.3	285.7
18.	3.3	222.4	55	40.3	286.9
19.	4.3	225.2	56	41.3	288.1
20.	5.3	227.9	57	42.3	289.1
21.	6.3	230.5	58	43.3	290.3
22.	7.3	233.0	59	44.3	291.4
23.	8.3	235.4	60	45.3	292.5

Absolute Pressure Lbs. Sq. In.	Pressure Above Atmosphere Lbs. Sq. In.	Temperature Degrees Fahrenheit	Absolute Pressure Lbs. Sq. In.	Pressure Above Atmosphere Lbs. Sq. In.	Temperature Degrees Fahrenheit
61	46.3	293.6	107	92.3	332.5
62	47.3	294.7	108	93.3	333.2
63	48.3	295.7	109	94.3	333.9
64	49.3	296.8	110	95.3	334.5
65	50.3	297.8	111	96.3	335.2
66	51.3	298.8	112	97.3	335.9
67	52.3	299.8	113	98.3	336.5
68	53.3	300.8	114	99.3	337.2
69	54.3	301.8	115	100.3	337.8
70	55.3	302.7	116	101.3	338.5
71	56.3	303.7	117	102.3	339.1
72	57.3	304.6	118	103.3	339.7
73	58.3	305.6	119	104.3	340.4
74	59.3	306.5	120	105.3	341.
75	60.3	307.4	121	106.3	341.6
76	61.3	308.3	122	107.3	342.2
77	62.3	309.2	123	108.3	342.9
78	63.3	310.1	124	109.3	343.5
79	64.3	310.9	125	110.3	344.1
80	65.3	311.8	126	111.3	344.7
81	66.3	312.7	127	112.3	345.3
82	67.3	313.5	128	113.3	345.9
83	68.3	314.4	129	114.3	346.5
84	69.3	315.2	130	115.3	367.
85	70.3	316.0	131	116.3	347.6
86	71.3	316.8	132	117.3	348.2
87	72.3	317.7	133	118.3	348.8
88	73.3	318.5	134	119.3	349.4
89	74.3	319.3	135	120.3	350.
90	75.3	320.	136	121.3	350.5
91	76.3	320.8	137	122.3	351.1
92	77.3	321.6	138	123.3	351.8
93	78.3	322.4	139	124.3	352.2
94	79.3	323.1	140	125.3	352.8
95	80.3	323.9	141	126.3	353.3
96	81.3	324.6	142	127.3	353.9
97	82.3	325.4	143	128.3	354.4
98	83.3	326.1	144	129.3	355.
99	84.3	326.8	145	130.3	355.5
100	85.3	327.6	146	131.3	356.
101	86.3	228.3	147	132.3	356.6
102	87.3	329.	148	133.3	357.1
103	88.3	329.7	149	134.3	357.6
104	89.3	330.4	150	135.3	358.2
105	90.3	331.1	151	136.3	358.7
106	91.3	331.8	152	137.3	359.2

Absolute Pressure Lbs. Sq. In.	Pressure Above Atmosphere Lbs. Sq. In.	Temperature Degrees Fahrenheit	Absolute Pressure Lbs. Sq. In.	Pressure Above Atmosphere Lbs. Sq. In.	Temperature Degrees Fahrenheit
153	138.3	359.7	198	183.3	380.7
154	139.3	360.2	199	184.3	381.2
155	140.3	360.7	200	185.3	381.6
156	141.3	361.3	201	186.3	382.
157	142.3	361.8	202	187.3	382.4
158	143.3	362.3	203	188.3	382.8
159	144.3	362.8	204	189.3	383.2
160	145.3	363.3	205	190.3	383.7
161	146.3	363.8	206	191.3	384.1
162	147.3	364.3	207	192.3	384.5
163	148.3	364.8	208	193.3	384.9
164	149.3	365.3	209	194.3	385.3
165	150.3	365.7	210	195.3	385.7
166	151.3	366.2	211	196.3	386.1
167	152.3	366.7	212	197.3	386.5
168	153.3	367.2	213	198.3	386.9
169	154.3	367.7	214	199.3	387.3
170	155.3	368.2	215	200.3	387.7
171	156.3	368.6	216	201.3	388.1
172	157.3	369.1	217	202.3	388.5
173	158.3	369.6	218	203.3	388.9
174	159.3	370.	219	204.3	389.3
175	160.3	370.5	220	205.3	389.7
176.	161.3	371.	230	215.3	393.6
177	162.3	371.4	240	225.3	397.3
178	163.3	371.9	250	235.3	400.9
179	164.3	372.4	260	245.3	404.4
180	165.3	372.8	270	255.3	407.8
181	166.3	373.3	280	265.3	411.
182	167.3	373.7	290	275.3	414.2
183	168.3	374.2	300	285.3	417.4
184	169.3	374.6	350	335.3	432.
185	170.3	375.1	400	385.3	449.9
186	171.3	375.5	450	435.3	456.6
187	172.3	375.9	500	485.3	467.4
188	173.3	376.4	550	535.3	477.5
189	174.3	376.9	600	585.3	486.9
190	175.3	377.3	650	635.3	495.7
191	176.3	377.7	700	685.3	504.1
192	177.3	378.2	750	735.3	512.1
193	178.3	378.6	800	785.3	519.6
194	179.3	379.	850	835.3	526.8
195	180.3	379.5	900	885.3	533.7
196	181.3	380.	950	935.3	540.3
197	182.3	380.3	1000	985.3	546.8

Standard Line Pipe

Nominal Inside Diameter	Actual Outside Diameter	Nominal Thick-ness	Nominal Weight per Foot in Pounds	Number of Threads per Inch of Screw
2	2.375	.154	3.609	11½
2½	2.875	.204	5.739	8
3	3.5	.217	7.536	8
3½	4.	.226	9.001	8
4	4.5	.237	10.665	8
4½	5.	.246	12.49	8
5	5.563	.259	14.502	8
6	6.625	.28	18.762	8
7	7.625	.301	23.271	8
8	8.625	.281	25.00	8
8	8.625	.322	28.177	8
9	9.625	.344	33.701	8
10	10.75	.2865	32.00	8
10	10.75	.3145	35.00	8
10	10.75	.366	40.065	8
12	12.75	.340	45.00	8
12	12.75	.375	48.985	8

Standard Wrought Steam, Gas and Water Pipe

Black and Galvanized—Iron and Steel—Weight, Usual Variation of 5 Per Cent.

Nom'l Inside Diameter	Price per Foot	Nominal Outside Diameter	Thickness	Nominal Weight per Foot	No. of Threads per Inch of Screw
⅛	.05½	.405	.068	0.24	27
¼	.05½	.540	.088	0.42	18
⅜	.05½	.675	.091	0.56	18
½	.08½	.840	.109	0.84	14
¾	.11½	1.05	.113	1.12	14
1	.16½	1.315	.134	1.67	11½
1¼	.22½	1.66	.140	2.24	11½
1½	.27	1.90	.145	2.68	11½
2	.36	2.375	.154	3.61	11½
2½	.57½	2.875	.204	5.74	8
3	.75½	3.500	.217	7.54	8
3½	.95	4.000	.226	9.00	8
4	1.08	4.500	.237	10.66	8
4½	1.30	5.000	.246	12.49	8
5	1.45	5.563	.259	14.50	8
6	1.88	6.625	.280	18.76	8
7	2.35	7.625	.301	23.27	8
8	2.50	8.625	.276	25.00	8
8	2.82	8.625	.322	28.18	8
9	3.40	9.625	.344	33.70	8
10	3.20	10.75	.278	32.00	8
10	3.50	10.75	.306	35.00	8
10	4.00	10.75	.366	40.00	8
11	4.50	11.75	.375	45.00	8
12	4.50	12.75	.328	45.00	8
12	4.90	12.75	.375	49.00	8
13	5.75	14.00	.375	56.10	8
14	6.50	15.00	.375	60.70	8
15	7.00	16.00	.375	64.90	8

The standard weight for 8, 10 and 12 in. pipe is: 8 in., 25 lb.; 10 in., 35 lb., and 12 in., 45 lb. pipe, respectively.

Nominal Weight in Pounds per Foot of Standard Thicknesses of Large Sizes O. D. Pipe

O. D. inches	¼ in. thick	9/32 in. thick	5/16 in. thick	11/32 in. thick	⅜ in. thick
14	36.75	45.72	54.61	63.42	72.16
15	39.42	49.06	58.62	68.10	77.50
16	42.09	52.40	62.63	72.78	82.85
17	44.76	55.74	66.64	77.46	88.19
18	47.44	59.08	70.65	82.14	93.54
20	52.78	65.76	78.67	91.49	104.2
21	55.45	69.10	82.68	96.17	109.6
22	.....	72.44	86.68	100.8	114.9
24	.....	79.13	94.70	110.2	125.6
26	.....	.....	102.7	119.5	136.3
28	.....	.....	110.7	128.9	147.0
30	.....	.....	.....	138.2	157.7

O. D. inches	13/32 in. thick	7/16 in. thick	15/32 in. thick	½ in. thick
14	80.80	89.36	97.84	106.2
15	86.81	96.03	105.2	114.2
16	92.83	102.7	112.5	122.2
17	98.84	109.4	119.9	130.3
18	104.8	116.1	127.2	138.3
20	116.9	129.4	141.9	154.3
21	122.9	136.1	149.3	162.3
22	128.9	142.8	156.6	170.3
24	140.9	156.2	171.3	186.3
26	152.9	169.5	186.0	202.4
28	165.0	182.9	200.7	218.4
30	177.0	196.3	215.4	234.4

This pipe is shipped in random lengths, plain ends, unless otherwise ordered.

List price of pipe is 10c. per pound, or $200.00 per ton of 2000 pounds.

Standard Extra Strong Pipe

Diameter.			Thick-ness.	Circumference.		Transverse Areas.			Nom. Wgt. per ft. lbs.	Threads per In.
Nom.	External.	Internal.		External.	Internal.	External.	Internal.	Metal.		
⅛	.405	.205	.100	1.272	.644	.129	.033	.096	.29	27
¼	.540	.294	.123	1.696	.924	.229	.068	.161	.54	18
⅜	.675	.421	.127	2.121	1.323	.358	.139	.219	.74	18
½	.840	.542	.149	2.639	1.703	.554	.231	.323	1.09	14
¾	1.050	.736	.157	3.299	2.312	.866	.425	.441	1.39	14
1	1.315	.951	.182	4.131	2.988	1.358	.710	.648	2.17	11½
1¼	1.660	1.272	.194	5.215	3.996	2.164	1.271	.893	3.00	11½
1½	1.900	1.494	.203	5.969	4.694	2.835	1.753	1.082	3.63	11½
2	2.375	1.933	.221	7.461	6.073	4.430	2.935	1.495	5.02	11½
2½	2.875	2 315	.280	9.032	7.273	6.492	4.209	2.283	7.67	8
3	3.500	2.892	.304	10.996	9.086	9.621	6.569	3.052	10.25	"
3½	4.000	3.358	.321	12.566	10.549	12.566	8.856	3.710	12.47	"
4	4.500	3.818	.341	14.137	11.995	15.904	11.449	4.455	14.97	"
4½	5.000	4.280	.360	15.708	13.446	19.635	14.387	5.248	18.22	"
5	5.563	4.813	.375	17.477	15.120	24.306	18.193	6.113	20.54	"
6	6.625	5.751	.437	20.813	18.067	34.472	25.976	8.496	28.58	"
7	7.625	6.625	.500	23.955	20.813	45.664	34.472	11.192	37.67	"
8	8.625	7.625	.500	27.096	23.955	58.426	45.664	12.762	43.00	"
9	9.625	8.625	.500	30.238	27.096	72.760	58.426	14.334	48.25	"
10	10.750	9.750	.500	33.772	30.631	90.763	74.662	16.101	54.25	"
12	12.750	11.750	.500	40.055	36.914	127.68	108.43	19.25	65.00	"

Allow variation in weight per foot of 5 per cent. above and 5 per cent. below standard. Cannot cut to length closer than $\frac{1}{16}$ inch. Shipped plain ends unless otherwise ordered. Where Extra Strong Pipe is ordered with threads and couplings, our regular line pipe couplings will be furnished, unless otherwise specified.

Standard Double Extra Strong Pipe

Diameter.			Thickness.	Circumference.		Transverse Areas.			Nom. Wgt. per ft. lbs.	Threads per In.
Nom.	External.	Internal.		External.	Internal.	External.	Internal.	Metal Area.		
½	.840	.244	.298	2.639	.767	.554	.047	.507	1.7	14
¾	1.050	.422	.314	3.299	1.326	.866	.140	.726	2.44	14
1	1.315	.587	.364	4.131	1.844	1.358	.271	1.087	3.65	11½
1¼	1.660	.885	.388	5.215	2.780	2.164	.615	1.549	5.2	11½
1½	1.900	1.088	.406	5.969	3.418	2.835	.930	1.905	6.4	11½
2	2.375	1.491	.442	7.461	4.684	4.430	1.744	2.686	9.02	11½
2½	2.875	1.755	.560	9.032	5.514	6.492	2.419	4.073	13.68	8
3	3.500	2.284	.608	10.996	7.176	9.621	4.097	5.524	18.56	"
3½	4.000	2.716	.642	12.566	8.533	12.566	5.794	6.772	22.75	"
4	4.500	3.136	.682	14.137	9.852	15.904	7.724	8.180	27.48	"
4½	5.000	3.564	.718	15.708	11.197	19.635	9.976	9.659	32.53	"
5	5.563	4.063	.750	17.477	12.764	24.306	12.965	11.341	38.12	"
6	6.625	4.875	.875	20.813	15.315	34.472	18.665	15.807	53.11	"
7	7.625	5.875	.875	23.955	18.457	45.664	27.109	18.555	62.38	"
8	8.625	6.875	.875	27.096	21.598	58.426	37.122	21.304	71.62	"

Allow variation of 5% above and 5% below standard in weight per foot.

Table of Expansion of Wrought Iron Pipe

Temperature of the air when the pipe is fitted, Degrees F.	Length of pipe when fitted, Feet	Length of pipe when heated to							
		215° F.		265° F.		297° F.		338° F.	
		Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
Zero	100	100	1.72	100	2.12	100	2.31	100	2.70
32	100	100	1.47	100	1.78	100	2.12	100	2.45
42	100	100	1.21	100	1.61	100	1.87	100	2.19

Heating Surfaces

STANDARD WEIGHT PIPE.			EXTRA STRONG PIPE.			DBLE. EX. STRONG PIPE.		
Length of Pipe in Ft. per Sq. Ft. of			Length of Pipe in Ft. per Sq. Ft. of			Length of Pipe in Ft. per Sq. Ft. of		
Size.	External Surface.	Internal Surface.	Size.	External Surface.	Internal Surface.	Size.	External Surface.	Internal Surface.
⅛	9.44	14.2	⅛	9.44	18.63	½	4.55	15.67
¼	7.07	10.5	¼	7.07	12.99	¾	3.64	9.05
⅜	5.66	7.76	⅜	5.66	9.07	1	2.90	6.51
½	4.55	6.15	½	4.55	7.05	1¼	2.30	4.32
¾	3.64	4.64	¾	3.64	5.11	1½	2.01	3.51
1	2.90	3.66	1	2.90	4.02	2	1.61	2.56
1¼	2.30	2.77	1¼	2.30	3.00	2½	1.33	2.18
1½	2.01	2.33	1½	2.01	2.56	3	1.09	1.67
2	1.61	1.85	2	1.61	1.97	3½	.955	1.41
2½	1.33	1.55	2½	1.33	1.65	4	.849	1.22
3	1.09	1.25	3	1.09	1.33	4½	.764	1.07
3½	.955	1.08	3½	.955	1.14	5	.687	.94
4	.849	.949	4	.849	1.00	6	.577	.78
4½	.764	.848	4½	.764	.893	7	.501	.65
5	.687	.757	5	.687	.793	8	.443	.55
6	.577	.630	6	.577	.664	....	....	....
7	.501	.544	7	.501	.598	....	....	....
8	.443	.478	8	.443	.502	....	....	....
9	.397	.427	9	.397	.443	....	....	....
10	.355	.381	10	.355	.399	....	....	....
11	.325	.348	....	....	....	....	....	....
12	.299	.319	12	.299	.325	....	....	....

Pipe Bends

The attached table gives the advisable radius and the greatest and least radii to which standard thickness pipe may be bent.

If the radius must be reduced from the minimum given in the table, the thickness of the pipe must be increased. For such bends it is best to submit sketch.

When the radius is greater than the maximum given in the list, the bend is apt to look like a series of kinks, owing to the bender having to take short heats, unless the radius is so great that the pipe may be bent cold.

With the welded flanges there must be a short straight length of pipe adjacent to each flange. On sizes under 4 inches this should equal, at least, one and a half diameters. On sizes over 4 inches it should equal, at least, one diameter of the pipe. In all cases it is better if equal to two diameters of straight pipe.

Pipe Size Inches	Minimum Radius Inches	Maximum Radius Inches	Advisable Radius Inches
2½	10	25	15
3	12	30	18
3½	14	35	21
4	16	40	24
4½	18	45	27
5	20	50	30
6	24	60	36
7	28	70	42
8	32	80	48
9	36	90	54
10	40	100	60
11	44	110	66
12	48	120	72
14 o. d.	60	140	84
15 o. d.	68	145	90
16 o. d.	76	150	100
18 o. d.	90	165	125
20 o. d.	120	180	150
22 o. d.	132	198	165
24 o. d.	144	216	180

Standard Dimensions of Couplings for Line Pipe

Size of Pipe, Nominal Inside Diameter	Inside Diameter of Coupling	Outside Diameter of Coupling	Length of Coupling	Thread per Inch of Screw.	Average Weight of Coupling in Pounds.
Inches.	Inches.	Inches.	Inches.		
¼	17/32	21/32	1 5/16	18	.06
⅜	23/32	27/32	1 5/8	18	.17
½	29/32	1 5/32	1 13/16	14	.29
¾	1 5/16	1 3/8	2 1/16	14	.41
1	1 11/32	1 5/8	2 5/16	11½	.64
1¼	1½	2 1/8	2 13/16	11½	1.10
1½	1 29/32	2 5/32	2 13/16	11½	1.18
2	2 5/32	2 7/8	3¼	11½	2.50
2½	2 19/32	3 7/16	3¾	8	3.12
3	3 7/32	4 1/16	3¾	8	3.85
3½	3¾	4 23/32	4 3/16	8	5.00
4	4 7/32	5 5/16	4 3/16	8	6.50
4½	4 23/32	5⅝	4 3/16	8	7.70
5	5¼	6 5/16	5⅛	8	11.21
6	6 5/16	7 13/32	5⅛	8	12.00
7	7 11/32	8 15/32	6⅛	8	14.75
8	8 11/32	9 9/16	5⅛	8	23.25
9	9 11/32	10 9/16	6⅛	8	26.48
10	10⅜	11 11/16	6⅛	8	29.50
11	11⅜	12 11/16	6⅛	8	34.75
12	12 7/16	13⅞	6⅛	8	39.50
13	13 11/16	15 1/16	6⅛	8	46.00
14	14 23/32	16 5/16	6⅛	8	59.75
15	15 11/16	17¼	6⅛	8	62.25

Standard Dimensions of Couplings for Steam, Gas and Water Pipe. Black and Galvanized

Size of Pipe. Nominal Inside Diameter	Inside Diameter of Coupling	Outside Diameter of Coupling	Length of Coupling	Thread per Inch of Screw.	Average Weight of Coupling in Pounds.
Inches.	Inches.	Inches.	Inches.		
⅛	11/32	1 9/32	13/16	27	.031
¼	15/32	27/32	1 1/16	18	.046
⅜	27/32	27/32	1 1/16	18	.078
½	27/32	1	1 5/16	14	.124
¾	1 1/32	1 21/64	1 5/16	14	.250
1	1 11/32	1 5/8	1 13/16	11½	.455
1¼	1½	1 21/32	2⅛	11½	.562
1½	1¾	2 7/32	2⅜	11½	.800
2	2 7/32	2¼	2⅝	11½	1.250
2½	2 21/32	3 5/32	2⅞	8	1.757
3	3¼	3 15/16	3⅛	8	2.625
3½	3 25/32	4 7/16	3⅜	8	4.000
4	4 17/32	5	3⅝	8	4.125
4½	4¾	5½	3⅝	8	4.875
5	5 5/32	6 7/32	4⅛	8	8.437
6	6 11/32	7 5/16	4⅛	8	10.625
7	7⅜	8 5/16	4⅛	8	11.270
8	8⅜	9 5/16	4⅝	8	15.150
9	9 7/16	10⅜	5⅛	8	17.820
10	10 7/16	11 21/32	6⅛	8	27.700
11	11 15/32	12 21/32	6⅛	8	33.250
12	12 7/16	13⅞	6⅛	8	43.187
13	13 11/16	15 1/16	6⅛	8	49.280
14	14 23/32	16⅜	6⅛	8	63.270
15	15 11/16	17⅜	6⅛	8	66.000

General Notes on Return Tubular Boilers

Horse-Power	10	12	12	15	20	20	25	30
Dimensions	30 x 7	30 x 8	36 x 7	36 x 8	36 x 10	42 x 8	42 x 10	44 x 10
Thickness of Shell Plates for 100 Lbs. Pressure	¼	¼	¼	¼	¼	5/16	5/16	5/16
Thickness of Heads for 100 Lbs. Pressure	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16
Diameter and Height of Dome, if used	18 x 20	18 x 20	20 x 22	20 x 22	20 x 22	22 x 24	22 x 24	24 x 24
Number and Diameter of Tubes	20–3″	20–3″	25–3″	28–3″	28–3″	38–3″	38–3″	46–3″
Size of Main Steam Outlet	2	2	2	2	2	2	2½	2½
Size of Pop Safety Valve	1	1¼	1¼	1¼	1¼	1¼	1½	1½
Size of Check and Feed Valves	1	1	1¼	1¼	1¼	1¼	1¼	1½
Size of Blow-off Valve	1	1	1¼	1¼	1¼	1¼	1¼	1½
Width and Length of Grate Surface	30 x 36	30 x 36	36 x 36	36 x 36	36 x 42	42 x 36	42 x 42	44 x 42
Size of Stack for One Boiler	14 x 28	14 x 28	16 x 24	16 x 28	16 x 35	20 x 28	20 x 35	22 x 35
Weight of Half Front Boiler, complete.....about	3325	3450	3925	4275	4900	5700	6445	7125
Weight of Full Front Boiler, complete.....about	....	....	....	....	....	....	....	....
	4040	4365	4400	4750	5375	6400	7125	7775
Approximate Number of Red Bricks required for Single Half Front Setting	4800	5300	5200	5700	6300	6200	7200	7500
Fire Bricks for Same Setting	440	500	470	540	600	600	730	790
Approximate Number of Red Bricks required for Full Front Setting	5800	6200	6300	6750	7800	7700	8900	9000
Fire Bricks for Same Setting	490	550	580	640	750	740	860	900
Standard Number of 3″, 3½″ and 4″ tubes which may be substituted, one for another: 3″	20	20	25	28	28	38	38	46
3½″	16	16	20	22	22	30	30	36
4″	....	....	....	....	....	....	....	....

General Notes on Return Tubular Boilers

35	40	40	45	50	60	60	70	80	100	125	150	175	200
44 x 12	44 x 14	48 x 12	48 x 14	54 x 12	54 x 15	60 x 12	60 x 14	60 x 16	66 x 16	72 x 16	72 x 18	78 x 18	84 x 18
5/16	5/16	5/16	5/16	5/16	5/16	11/32	11/32	11/32	3/8	7/16	7/16	7/16	11/32
						7/16	7/16	7/16	7/16	1/2	1/2	1/16	1/16
24 x 24	24 x 24	28 x 28	28 x 28	30 x 34	30 x 34	32 x 36	34 x 36	32 x 36	36 x 40	36 x 40	36 x 40	36 x 40	36 x 40
46–3″	46–3″	52–3″	52–3″	54–3″	54–3″	72–3″	72–3″	44–4″	54–4″	70–4″	70–4″	88–4″	104–4″
2½	3	3	3	3	3½	4	4	4½	5	5	5	6	6
2	2	2	2½	2½	2½	2½	2½	3	3	3½	4	4½	5
1½	1½	1½	1½	1½	1½	1½	1½	1½	1½	2	2	2	2
1½	1½	1½	1½	1½	1½	1½	1½	2	2	2	2	2½	2½
44 x 48	44 x 54	48 x 48	48 x 54	54 x 48	54 x 54	60 x 48	60 x 54	60 x 54	66 x 54	72 x 54	72 x 60	78 x 60	84 x 60
22 x 40	22 x 50	24 x 40	24 x 50	26 x 40	26 x 50	28 x 40	28 x 50	28 x 60	32 x 60	34 x 60	34 x 60	38 x 60	40 x 60
7825	8650	8950	10500	10550	12325	12575	13975	15150	18975	22300	24200	27450	31150
5000	5600	5900	6550	7150	8550	8650	9700	10600	13400	16100	17950	20800	24000
3525	3725	3650	3950	4350	4725	4725	5075	5350	6325	6900	6950	8200	8700
8525	9325	9550	10500	11500	13275	13375	14775	15950	19525	23000	24900	29000	32700
8400	9300	8800	9700	10700	12500	11700	13000	14000	15400	16500	17800	19200	20200
920	1050	980	1080	1080	1200	1170	1300	1400	1580	1800	1900	2200	2400
10000	11000	10500	11500	12500	13800	13000	14000	15000	17000	18000	19000	21300	22500
1050	1175	1100	1250	1250	1450	1300	1450	1600	1800	1900	2000	2350	2550
46	46	52	52	54	54	72	72	72*	88*	....	....	....	....
36	36	42	42	44	44	54	54	54	66	86	86	....	....
....	....	....	....	....	....	44	44	44	54	70	70	88	104

General Notes on Return Tubular Boilers

Horse Power	50	60	60	70	80	100	125	150	175	200
Dimensions	54x12	54x15	60x12	60x14	60x16	66x16	72x16	72x18	78x18	84x18
Thickness of Shell Plates, 125 lbs. pressure..	5/16	5/16	11/32	11/32	11/32	3/8	7/16	7/16	7/16	15/32
Thickness of Heads, 125 lbs. pressure	7/16	7/16	7/16	7/16	7/16	7/16	1/2	1/2	7/16	7/16
Number and Diameter of Tubes	54–3″	54–3″	72–3″	72–3″	44–4″	54–4″	70–4″	70–4″	88–4″	104–4″
Type of Longitudinal Seams Usually Used..	———	Double	Butt St	rapped	and Tri	ple Riv	eted. —	———	Double Butt Quadruple	Strapped & Riveted.
Number of Hanger Loops (if used instead of Lugs)	4	4	4	4	4	4	4	4	4	4
Number of Steel Side Lugs	4	4	4	4	4	4	4	4	8	8
Size of Main Steam Outlet	3	3 1/2	4	4	4 1/2	5	5	5	6	6
Size of Pop Safety Valve	2 1/2	2 1/2	2 1/2	2 1/2	3	3	3 1/2	4	4 1/2	5
Size of Check and Feed Valve	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	2	2	2	2
Size of Blow-off Valve	1 1/2	1 1/2	1 1/2	1 1/2	2	2	2	2	2 1/2	2 1/2
Width and Length of Grate Surface	54x48	54x54	60x48	60x54	60x54	66x54	72x54	72x60	78x60	84x60
Size of Stack for One Boiler	26x40	26x50	28x40	28x50	28x60	32x60	34x60	34x60	38x60	40x60
Weight of Boiler with Smoke Extension and Flue Doors...about	6850	8150	8550	9600	10400	13200	16350	17800	21000	24200
Weight of Full Front Boiler, complete.about	11100	12775	12975	14375	15450	19075	22700	24200	29000	37200
Approximate Number of Red Bricks required for Single Half Front Setting	10700	12500	11700	13000	14000	15400	16500	17800	19200	20200
Fire Bricks for same Setting	1080	1200	1170	1300	1400	1580	1800	1900	2200	2400
Approximate Number of Red Bricks required for Full Front Setting	12500	13800	13000	14000	15000	17000	18000	19000	21300	22500
Fire Bricks for same Setting	1250	1450	1300	1450	1600	1800	1900	2000	2350	2550

General Notes on Return Tubular Boilers

Horse Power	50	60	60	70	80	100	125	150	175	200
Dimensions	54x12	54x15	60x12	60x14	60x16	66x16	72x16	72x18	78x18	84x18
Thickness of Shell Plates, 150 lbs. Pressure Thickness of Heads, 150 lbs. Pressure	3/8 7/16	3/8 7/16	7/16 1/2	7/16 1/2	7/16 1/2	11/16 1/2	1/2 7/16	1/2 7/16	11/16 5/8	9/16 5/8
Number and Diameter of Tubes	54–3″	54–3″	72–3″	72–3″	44–4″	54–4″	70–4″	70–4″	88–4″	104–4″
Type of Longitudinal Seams	Double	Butt St	rapped	and Tri	ple Riv	eted.	Double	Butt St Quadru	rapped ple Riv	and eted.
Number of Hanger Loops (if used instead of Lugs) Number of Steel Side Lugs	4 4	4 4	4 4	4 4	4 4	4 4	4 4	4 4	4 8	4 8
Size of Main Steam Outlet Size of Pop Safely Valve Size of Check and Feed Valves Size of Blow-off Valve	3 2½ 1½ 1½	3½ 2½ 1½ 1½	4 2½ 1½ 1½	4 2½ 1½ 1½	4½ 3 1½ 2	5 3 1½ 2	5 3½ 2 2	5 4 2 2	6 4½ 2 2½	6 5 2 2½
Width and Length of Grate Surface	54x48	54x54	60x48	60x54	60x54	66x54	72x54	72x60	78x60	84x60
Size of Stack (for One Boiler)	26x40	26x50	28x40	28x50	28x60	32x60	34x60	34x60	38x60	40x60
Weight of Boiler with Smoke Extension and Flue Doors...about Weight of Full Front Boiler, complete...about	7250 11500	8650 13275	9350 13775	10600 15375	11900 16950	14700 20525	18000 24400	19700 26100	22900 30900	26200 34700
Approximate Number of Red Bricks required for Single Half Front Setting Fire Bricks for same Setting	10700 1080	12500 1200	11700 1170	13000 1300	14000 1400	15400 1580	16500 1800	17800 1900	19200 2200	20200 2400
Approximate Number of Red Bricks required for Full Front Setting Fire Bricks for same Setting	12500 1250	13800 1450	13000 1300	14000 1450	15000 1600	17000 1800	18000 1900	19000 2000	21300 2350	22500 2550

Horse Power of an Engine

a equals area of piston in square inches.
p equals mean pressure of the steam on the piston per square inch.
v equals velocity of piston per minute in feet.

Then H. P. equals $\frac{a \times p \times v}{33000}$

The mean pressure in the cylinder when cutting off at

¼	stroke	equals	boiler	pressure	× 0.597
⅓	"	"	"	"	× 0.670
⅜	"	"	"	"	× 0.743
½	"	"	"	"	× 0.847
⅝	"	"	"	"	× 0.919
⅔	"	"	"	"	× 0.937
¾	"	"	"	"	× 0.966
⅞	"	"	"	"	× 0.992

To find the weight of the rim of the flywheel for an engine:

$$\frac{\text{Nominal H. P.} \times 2000}{\text{The square of the velocity of the circumference in feet per second.}}$$ equals weight in cwts.

Table for Converting Feet Head of Water into Pressure per Square Inch

Feet Head	Pounds per Square Inch	Feet Head	Pounds per Square Inch	Feet Head	Pounds per Square Inch
1	0.43	55	23.82	190	82.29
2	0.87	60	25.99	200	86.62
3	1.30	65	28.15	225	97.45
4	1.73	70	30.32	250	108.27
5	2.17	75	32.48	275	119.10
6	2.60	80	34.65	300	129.93
7	3.03	85	36.81	325	140.75
8	3.40	90	38.98	350	151.58
9	3.90	95	41.14	375	162.41
10	4.33	100	43.31	400	173.24
15	6.50	110	47.64	500	216.55
20	8.66	120	51.97	600	259.85
25	10.83	130	56.30	700	303.16
30	12.99	140	60.63	800	346.47
35	15.16	150	64.96	900	189.78
40	17.32	160	69.29	1000	433.09
45	19.49	170	73.63	.....	.....
50	21.65	180	77.96	.....	.....

Table for Converting Pressure per Square Inch into Feet Head of Water

Pounds per Square Inch	Feet Head	Pounds per Square Inch	Feet Head	Pounds per Square Inch	Feet Head
1	2.31	55	126.99	180	415.61
2	4.62	60	138.54	190	438.90
3	6.93	65	150.08	200	461.78
4	9.24	70	161.63	225	519.51
5	11.54	75	173.17	250	577.24
6	13.85	80	184.72	275	643.03
7	16.16	85	196.26	300	692.69
8	18.47	90	207.81	325	750.41
9	20.78	95	219.35	350	808.13
10	23.09	100	230.90	375	865.89
15	34.63	110	253.98	400	922.58
20	48.18	120	277.07	500	1154.48
25	57.72	125	288.62	.....	.....
30	69.27	130	300.16	.....	.....
35	80.81	140	323.25	.....	.....
40	92.36	150	346.34	.....	.....
45	103.90	160	369.43	.....	.....
50	115.45	170	392.52	.....	.....

Useful Information and Formulæ for Calculating Pump Problems

1. Diameter multiplied by 3.1416 = Circumference.

2. Circumference multiplied by 0.3183 = Diameter.

3. The square of the diameter multiplied by 0.7854 = Area.

4. A gallon of fresh water weighs 8⅓ lbs. and contains 231 cu. in.

5. A cubic foot of water weighs 62½ lbs. and contains 1,728 cu. in., or 7½ gals.

5. A cubic foot of water weighs 62½ lbs. and conminute.

7. To find the diameter of a pump cylinder required to move a given quantity of water per minute, the piston travel being 100 per minute, divide the number of gallons by four, then extract the square root and the result will be the diameter in inches.

8. To find the area of required pipe, the volume of water being known, multiply the number of cubic feet of water by 144 and divide the product by the velocity in feet per minute. This gives the area of pipe, from which it is easy to determine the diameter.

9. To find the velocity in feet per minute necessary to discharge a given volume of water in a given time, multiply the number of cubic feet of water by 144 and divide the product by the area of the pipe in inches.

10. With steam pumps the area of the steam piston multiplied by the steam pressure gives the total amount of pressure exerted. The area of the water piston multiplied by the pressure of water per square inch gives the resistance. A margin must be made between the power and resistance to move the pistons at the required speed, usually reckoned at from 25 to 40%.

D = Diameter of Cylinder in inches.

S = Length of Stroke in inches.

N = Total number of Strokes per minute.

G = Quantity in gallons per minute.

H = Height in feet water is elevated.

A = Area of Cylinder in square inches.

Area of Cylinder in square inchts = $D^2 \times .7854$.

Capacity of Pump per stroke in cubic inches = $S \times A$.

Capacity of Pump per stroke in gallons = $\frac{S \times A}{231}$

Capacity of Pump per stroke in cubic feet = $\frac{S \times A}{1728}$

Capacity of Pump per stroke in pounds = $\frac{S \times A \times 8\frac{1}{3}}{231}$

Capacity of Pump per minute in cubic inches = $S \times N \times A$.

Capacity of Pump per minute in gallons (G) = $\frac{S \times N \times A}{231}$

Capacity of Pump per minute in cubic feet = $\frac{S \times N \times A}{1728}$

Pressure per square inch in pounds of a column of water = $H \times 0.434$.

Horse-power required to elevate a given quantity of water per minute to a given height, not allowing for friction = $\frac{G \times H \times 8\frac{1}{3}}{33000}$

In figuring the actual horse-power required to operate a pump, the "friction head" should be added to the "actual head" or elevation.

Using the above formula and including the "friction head" will give the theoretical horse-power. To figure the actual horse-power required it is necessary to know the efficiency of the pump. To illustrate:

If the efficiency of a small pump is 33⅓%, the actual horse-power required is three times the theoretical.

If the efficiency is 50%, the actual horse-power is double the theoretical.

If the efficiency is 66⅔%, the actual horse-power is 1½ times the theoretical, etc.

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